MARCH 1952

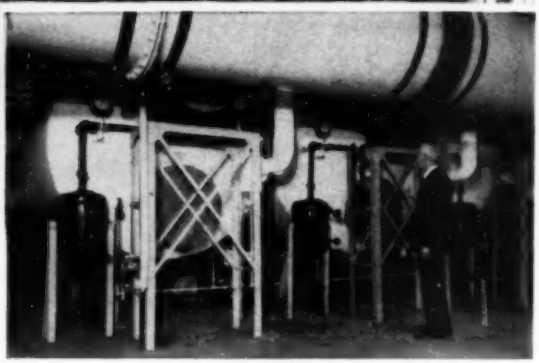
Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

95% of Gasoline Solvent Recovered

with COLUMBIA *Activated Carbon*

Trade-Mark



WRITE FOR BOOKLET

Send for our 16-page booklet "How 7 Industries Save $150,000,000 a year with COLUMBIA Activated Carbon" which tells how other companies have profited. A request on your letterhead will bring you a copy, without obligation. Write today.

CARBIDE AND CARBON CHEMICALS COMPANY

A Division of
Union Carbide and Carbon Corporation
30 East 42nd Street UCC New York 17, N. Y.

COLUMBIA
Activated Carbon

SOLVENT RECOVERY · CATALYSIS
GAS AND AIR PURIFICATION

A modern solvent recovery plant for The Garlock Packing Company, Palmyra, New York, using COLUMBIA Activated Carbon as the adsorbent, collects about 1,000 pounds of gasoline vapor per hour from the air and delivers it ready for re-use. The gasoline is vaporized during the manufacture of asbestos sheet packing and is recovered at lower cost and higher efficiency than is possible with any other commercial method. Operating records for a 10-month period since the plant started show an *overall* recovery efficiency of 95.9 per cent. In addition to the profitable recovery of gasoline, this installation also:

- improves the working conditions in the plant,
- helps reduce the hazards of handling gasoline vapors,
- avoids the discharge of large volumes of solvent-laden air into the atmosphere.

The special features of CARBIDE's automatic equipment and the high adsorptive capacity of COLUMBIA Activated Carbon make such performance possible for Garlock Packing.

If you vaporize solvents in your process, let CARBIDE help you conserve valuable solvents, improve processing conditions, and clean up exhaust air. We can supply you with a complete, automatic, instrument-controlled plant designed for your specific requirements with guaranteed operating efficiency to recover solvent vapors or purify industrial gases.

"Columbia" is a registered trade-mark of Union Carbide and Carbon Corporation

Volume 48
Number 3

Chemical Engineering Progress

MARCH
1952

OPINION AND COMMENT

Page

SINCERITY AND INTEGRITY IN PROFESSIONAL RELATIONS
J. H. Rushton 113

ENGINEERING SECTION

DESIGNING FOR MAINTENANCE
L. B. Woolfenden and R. C. Thiede 115

GENERALIZED GRAPHICAL METHOD FOR THE DESIGN OF FIXED BED CATALYTIC REACTORS
Thomas Baron 118

REACTION KINETICS IN A TUBULAR REACTOR
Thomas Baron, W. R. Manning, and H. F. Johnstone 125

THE EFFECT OF ORIENTATION AND SHAPE—On the Settling Velocity of Non-Isometric Particles in a Viscous Medium
J. F. Heiss and James Coull 133

EVAPORATION FROM DROPS
W. E. Ranz and W. R. Marshall, Jr. 141

THERMAL CONDUCTIVITY OF GRANULAR SOLIDS THROUGH WHICH GASES ARE FLOWING
D. F. Molino and J. O. Hougen 147

THE EVALUATION OF CENTRIFUGE PERFORMANCE
C. M. Ambler 150

NEWS

Page

SHOULD CHEMICAL ENGINEERING BE EXPORTED?
E. L. Piret 29

FRENCH LICK MEETING 30

INDUSTRIAL NEWS 32

LOCAL SECTION NEWS 41

DATA SERVICE 47-50

A.I.Ch.E. CANDIDATES 56

Page

SECRETARY'S REPORT 58

A LOCAL SECTION SPONSORS A LECTURE SERIES
D. S. Bruce 60

FUTURE MEETINGS 62

NEWS ABOUT PEOPLE..... 63

NECROLOGY 67

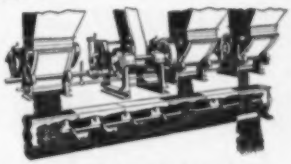
CLASSIFIED SECTION 68

Editor: F. J. Van Antwerpen ● **Publication Board:** W. I. Burt, Chairman; W. T. Nichols, Vice-Chairman; C. R. DeLong, S. L. Tyler, T. H. Chilton ● **Publication Committee:** W. T. Nichols, Chairman; W. C. Edmister, A. S. Foust, W. E. Lobo, R. L. Pigford, E. L. Piret, F. J. Van Antwerpen ● **Advertising Manager,** Lansing T. Dupree.

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania. Editorial and Advertising Offices, 120 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in *Chemical Engineering Progress* are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, $6.00; Canada, $6.50; Pan-American Union, $7.50; Other Foreign, $8.00. Single copies of *Chemical Engineering Progress* older than one year cost $1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1952 by American Institute of Chemical Engineers. Member of Audit Bureau of Circulations. *Chemical Engineering Progress* is indexed regularly by Engineering Index, Incorporated.

Stop Production Choke-ups
with a DRAVER FEEDER

YOU can automatically regulate material flow to production equipment with Draver Feeders. Even stubborn dry ingredients are fed at the *right rate* to get maximum production without overloading. No more choke-ups, wasted time and power, or operating inefficiency. Draver Feeders are made in 100 different sizes with capacities from minute quantities to thousands of pounds per hour—and in several models, to handle a wide variety of dry, powdered or granular materials. Our Engineers will gladly suggest the best installation for YOU. Will you check and mail the coupon today?



Draver Master Continuous Mixing Systems . . . for accurate, economical mixing and blending of dry ingredients under positive mechanical control. They assure "on formula" uniformity of the finished product. *Thousands* of successful installations prove their dependable operating efficiency.

TEAR OUT—PASTE ON LETTERHEAD AND MAIL TODAY!

B. F. GUMP CO.,
1311 So. Cicero Ave., Chicago 50, Ill.

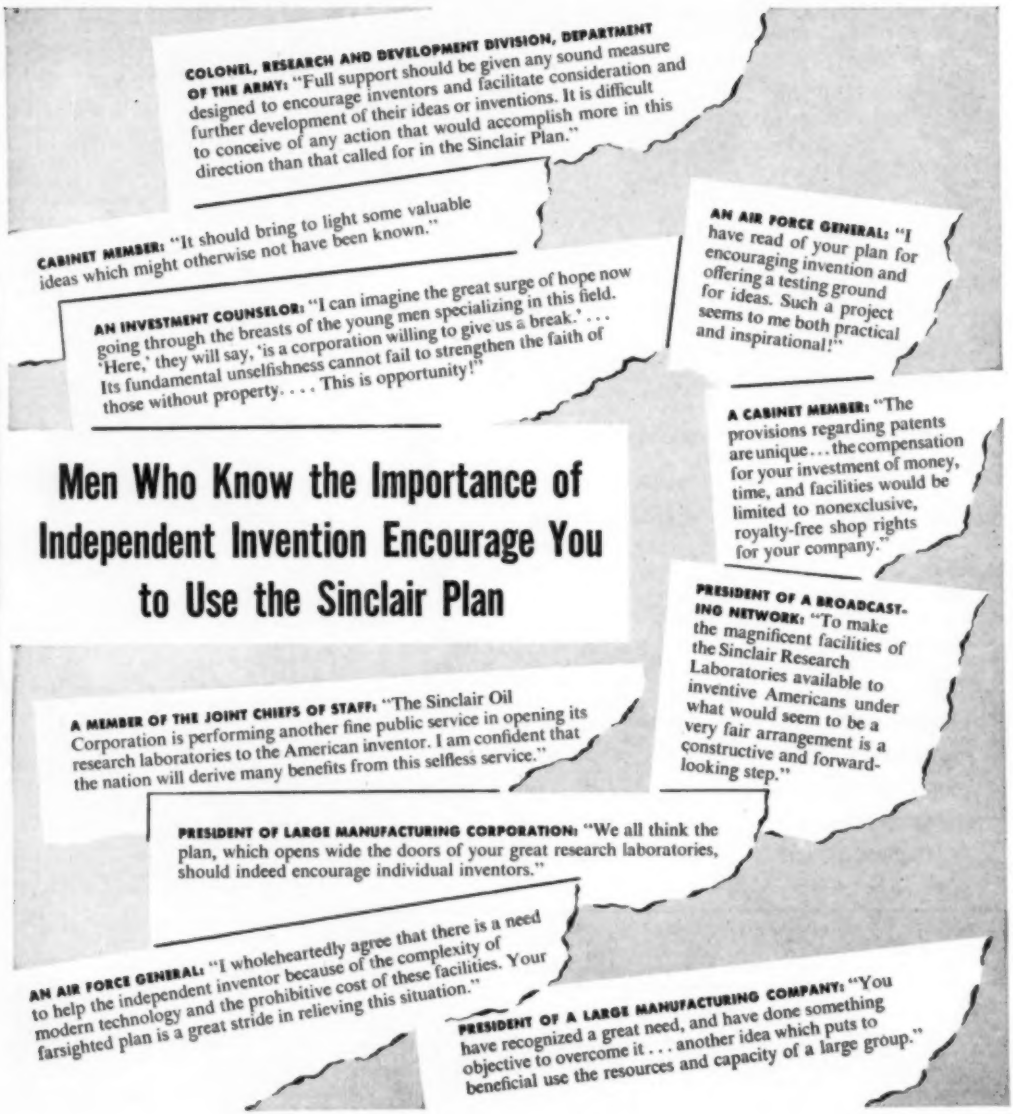
Gentlemen: Please send me descriptive literature and complete information on the GUMP-Built Equipment indicated below:

☐ BAR-NUN SIFTERS—grade, scalp or sift dry materials.
☐ DRAVER FEEDERS—accurate volume percentage feeding.
☐ DRAVER Continuous Mixing Systems—accurate, efficient mixing.
☐ VIBROX PACKERS—pack dry materials in bags, drums, barrels.
☐ NET WEIGHERS—automatic weights range from 3 oz. to 75 lbs.

B. F. GUMP CO.
Engineers and Manufacturers Since 1872

1311 SOUTH CICERO AVE.
CHICAGO 50, ILLINOIS

Have You Taken This Opportunity for


COLONEL, RESEARCH AND DEVELOPMENT DIVISION, DEPARTMENT OF THE ARMY: "Full support should be given any sound measure designed to encourage inventors and facilitate consideration and further development of their ideas or inventions. It is difficult to conceive of any action that would accomplish more in this direction than that called for in the Sinclair Plan."
CABINET MEMBER: "It should bring to light some valuable ideas which might otherwise not have been known."
AN INVESTMENT COUNSELOR: "I can imagine the great surge of hope now going through the breasts of the young men specializing in this field. 'Here,' they will say, 'is a corporation willing to give us a break.' . . . Its fundamental unselfishness cannot fail to strengthen the faith of those without property. . . . This is opportunity!"
AN AIR FORCE GENERAL: "I have read of your plan for encouraging invention and offering a testing ground for ideas. Such a project seems to me both practical and inspirational!"
A CABINET MEMBER: "The provisions regarding patents are unique . . . the compensation for your investment of money, time, and facilities would be limited to nonexclusive, royalty-free shop rights for your company."
Men Who Know the Importance of Independent Invention Encourage You to Use the Sinclair Plan
A MEMBER OF THE JOINT CHIEFS OF STAFF: "The Sinclair Oil Corporation is performing another fine public service in opening its research laboratories to the American inventor. I am confident that the nation will derive many benefits from this selfless service."
PRESIDENT OF A BROADCASTING NETWORK: "To make the magnificent facilities of the Sinclair Research Laboratories available to inventive Americans under what would seem to be a very fair arrangement is a constructive and forward-looking step."
PRESIDENT OF LARGE MANUFACTURING CORPORATION: "We all think the plan, which opens wide the doors of your great research laboratories, should indeed encourage individual inventors."
AN AIR FORCE GENERAL: "I wholeheartedly agree that there is a need to help the independent inventor because of the complexity of modern technology and the prohibitive cost of these facilities. Your farsighted plan is a great stride in relieving this situation."
PRESIDENT OF A LARGE MANUFACTURING COMPANY: "You have recognized a great need, and have done something objective to overcome it . . . another idea which puts to beneficial use the resources and capacity of a large group."

Chemical Engineering Progress is indexed regularly by Engineering Index, Incorporated.

Advantage of Independent Inventors?

If you have an idea for a new petroleum product—but do not have the facilities needed to develop it—the Sinclair Plan offers you laboratory help.

EIGHT months ago, Sinclair opened up a part of its great research laboratories to independent inventors who had ideas for new or improved petroleum products but who did not have the facilities needed to develop and profit by their ideas.

To date nearly 5,000 inventive people have submitted ideas to the laboratories; and the Sinclair Plan has become recognized as a service to inventors, the oil industry and the public. As a result we have made the Plan part and parcel of the long-range operation of our company.

If you have an idea for a new or improved petroleum product or application, you are invited to submit it to the Sinclair Research Laboratories. In your own interest, each idea must first be protected by a patent application or a patent.

If the laboratories select your idea for development, they will make a very simple arrangement with you: In return for the laboratories' work, Sinclair will receive the privilege of using the idea for its own companies, free from royalties. This in no way hinders the inventor from selling his idea to any of the hundreds of other oil companies for whatever he can get. Sinclair has no control over the inventor's sale of his idea to others, and has no participation in any of the inventor's profits through such dealings.

HOW TO PARTICIPATE: Instructions are contained in an Inventor's Booklet. Write to W. M. Flowers, Executive Vice-President, Sinclair Research Laboratories, Inc., 600 Fifth Avenue, New York 20, N. Y.

IMPORTANT: *Please do not send in any ideas until you have sent for and received the instructions.*

Nine buildings of the Sinclair Research Laboratories at Harvey, Ill.

SINCLAIR—for Progress

Uniformity

GLC Anodes for the electrolytic industry are uniform—they stand the test of comparison.

Baking Furnaces
Morganton
N. C. Plant

Plants:
Niagara Falls, N. Y.
Morganton, N. C.

Great Lakes Carbon Corporation

GLC

ELECTRODE DIVISION · NIAGARA FALLS, N. Y.

Sales Offices:
Niagara Falls, N. Y.
New York, N. Y.
Chicago, Ill.
Pittsburgh, Pa.

Representatives:
Birmingham, Ala.
Wilmington, Cal.

PRODUCTS OF GREAT LAKES CARBON CORPORATION

Electrode Division
Graphite anodes. Graphite and amorphous carbon electrodes. Carbon and graphite specialties.

Oil and Gas Division
Crude petroleum and natural gas.

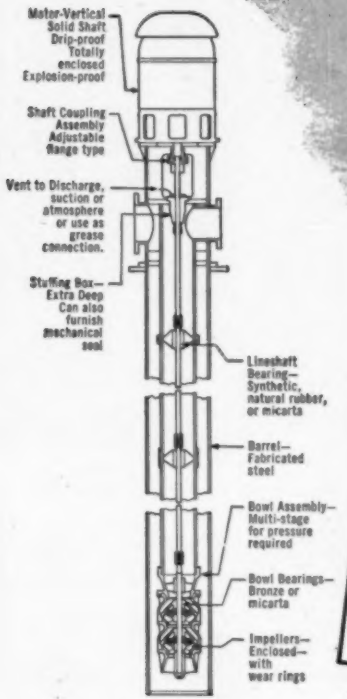
Carbon Division
Petroleum coke. Calcined petroleum coke. Industrial carbons.

Dicalite Division
Diatomaceous silica for filter-aids, fillers and insulating uses.

Perlite Division
Perlite lightweight aggregates and products for the building, oil, foundry and other industries. Perlite ore.

Merchant Coke Plant
Premium foundry and industrial coke. Coke co-products.

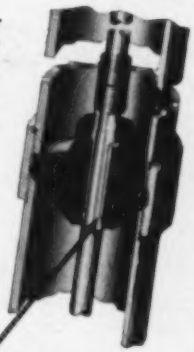
NOTES FROM THE PUMP ENGINEER'S HANDBOOK


Motor-Vertical Solid Shaft Drip-proof Totally enclosed Explosion-proof
Shaft Coupling Assembly Adjustable flange type
Vent to Discharge, suction or atmosphere or use as grease connection.
Stuffing Box—Extra Deep Can also furnish mechanical seal
Lineshaft Bearing—Synthetic, natural rubber, or micarta
Barrel—Fabricated steel
Bowl Assembly—Multi-stage for pressure required
Bowl Bearings—Bronze or micarta
Impellers—Enclosed—with wear rings

This unit is a vertical turbine type pump designed to handle volatile liquids and liquids near the boiling point. Both suction and discharge are above grade and the pump bowls are enclosed in a steel barrel. This pump offers many advantages where there is a limited NPSH... Bowls are easily set low enough for proper submergence... Expensive dry sumps are eliminated... Nothing to lubricate except driver bearing... Efficiency is comparable with horizontal centrifugals at low heads and is often greater at high heads.

SHAFT WEAR CAN'T HAPPEN to a Johnston Water-Lubricated Pump!

Here's another QUALITY feature that makes Johnston Water-Lubricated Turbine Pumps a good investment. The renewable stainless steel sleeves which shroud the line-shaft at all points of bearing contact make it impossible for sand or other abrasives to damage the shaft. Sure, the sleeve and bearings wear on a Johnston just like they do on any pump... but think of the savings on parts and labor alone when you simply replace a sleeve instead of a complete section of shafting. What's more, you don't need a lot of special tools to do the job! Do it at the pump site... just unscrew the old sleeve and thread on the new!!!



LITTLE DETAILS LIKE THE RENEWABLE SHAFT SLEEVE MAKE JOHNSTON PUMPS BETTER!!!

Trained hydraulic engineers are available at your nearest Johnston Dealer or at the Johnston factory to furnish detailed information, proposals and anything else necessary to meet your particular pumping equipment needs.

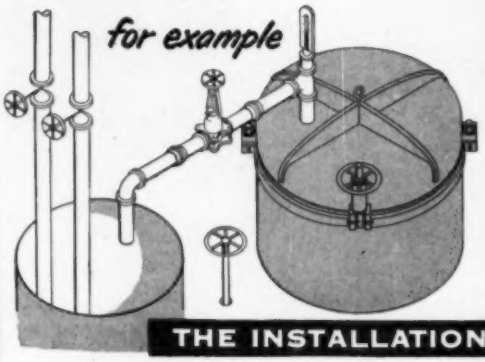
THERE'S A JOHNSTON PUMP FOR EVERY PURPOSE

Sizes range from 4 to 32 inches; single- or multi-stage; 2 to 1000 H.P.; capacities to 10,000 G.P.M.; lifts to 1000 feet; for liquid temperatures to 400° F.

JOHNSTON PUMP COMPANY
3272 EAST FOOTHILL BLVD., PASADENA 8, CALIFORNIA

Is Corrosion Your Valve Problem?

...on Acid Solutions Like This, for example



THE INSTALLATION

In acid dye line to package dye machine at Phoenix Dye Works, Chicago, Ill.

VALVE SERVICE RATINGS

SUITABILITY:	O.K. for acid dye solutions
MAINTENANCE COST:	None; lubrication only
CORROSION-RESISTANCE:	Excellent; No sign of corrosion
SERVICE LIFE:	Good as new after 3 years' Constant service
OPERATING RESULTS:	No leakage; no production loss easier valve operation
PRICE:	In line with good alloy valves
AVAILABILITY:	Regular item in Crane alloy line

THE HISTORY

Various valves and cocks previously tried in this service gave much trouble with leakage and sticking, needing excessive maintenance and lasting only 1 to 2 months at best. Valve almost constantly in contact with varying acid dye solutions at temperatures ranging from 50 to 210 degrees F. Operated about 100 times daily, often with disc in throttling position.

Since installing a Crane No. 18850 all 18-8 Mo Stainless Steel Plug Gate Valve—more than 3 years ago—user reports: no leakage through valve . . . no sign of corrosion . . . no maintenance expense . . . unusually easy operation. Highly enthusiastic about Crane Plug Gate Valves.

THE VALVE

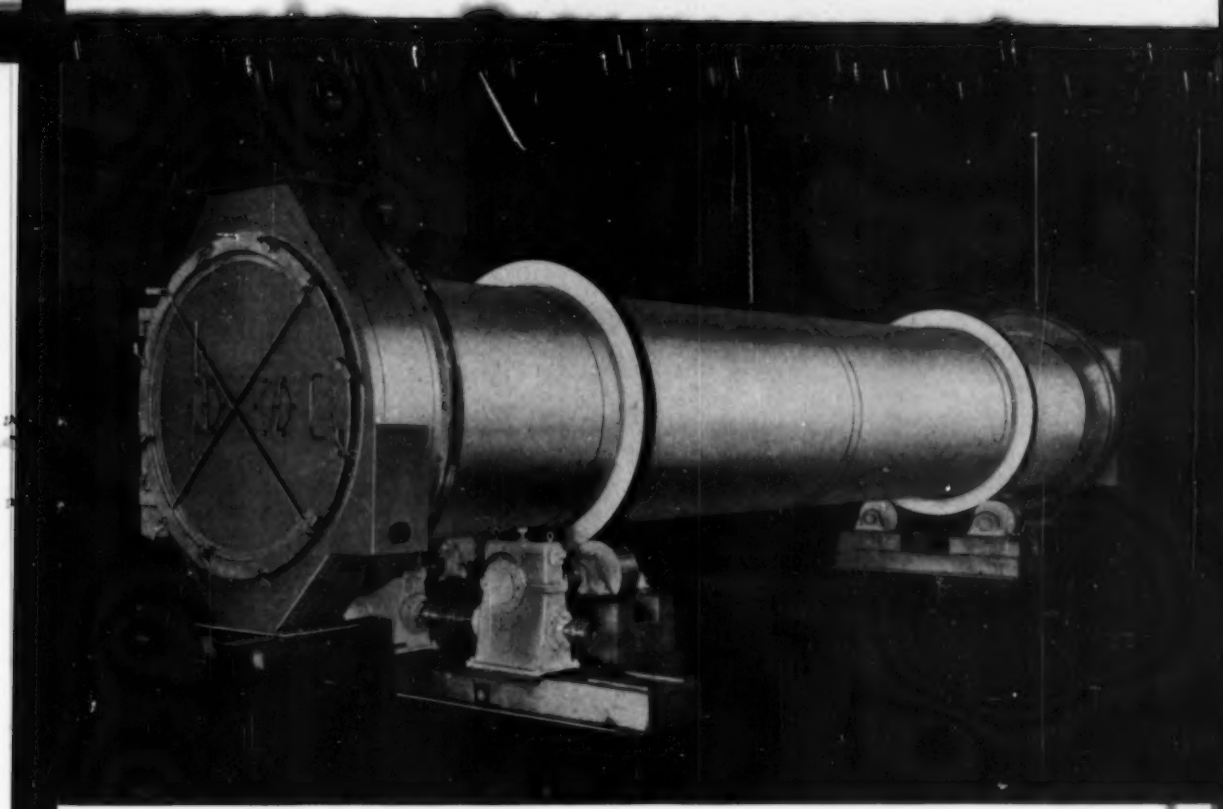
One of the finest in the Crane line for corrosive service—No. 18850 Plug Gate—with 18-8 Mo stainless steel in all parts exposed to flow, including packing gland. Circular tapered plug seating performs with equally high efficiency on precise throttling or where unrestricted flow is needed. These valves also made in all Monel. See your Crane Catalog or Crane Representative.

The Complete Crane Line Meets All Valve Needs. That's Why,
More Crane Valves Are Used Than Any Other Make!

CRANE VALVES

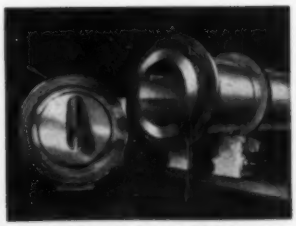
CRANE CO., *General Offices:* 836 S. Michigan Ave., Chicago 5, Illinois
Branches and Wholesalers Serving All Industrial Areas

VALVES • FITTINGS • PIPE • PLUMBING • HEATING



stainless steel *Plastics Dryer*

prevents product contamination



Labyrinth Seal on 60" x 32' 0" Stainless Steel Plastics Dryer showing the Mirror-like Finish on the Shell and Flights.

Special Steam Jacketed Batch Dryer showing Dustless Discharge to Screw Conveyor and Condenser where Fines are Reclaimed from Vapors.

● Fabricated entirely of stainless steel, the 60" x 32' 0" dryer pictured above, is probably one of the most costly direct heat rotary dryers ever built. The entire interior, including the flights, is polished to a mirror-like finish, and is easily accessible for cleaning. Feed and discharge breechings and inspection doors are also of stainless steel polished on the inside. Air used in drying is filtered and the discharged air is passed through a special high efficiency dust collector, of stainless steel construction. Fabricated in our extensive machine and structural shops this dryer, built to prevent contamination and spoilage between different batches—and colors—of a well known plastic, reflects the ability of Bartlett-Snow to meet fully the requirements of even the most exacting heat engineering problems.

DESIGNERS
ENGINEERS

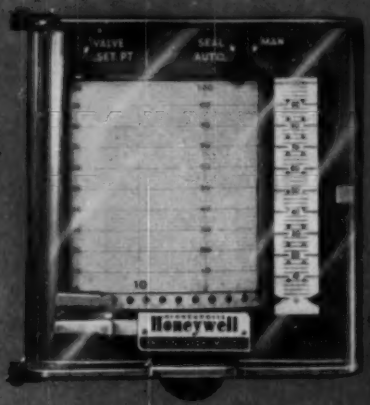
BARTLETT-SNOW
CLEVELAND 5, OHIO

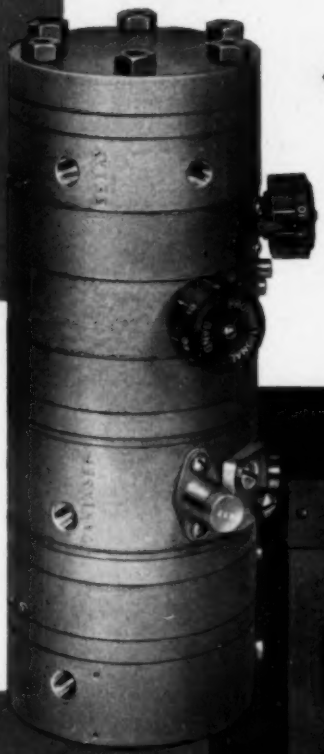
FABRICATORS
ERECTORS

Dryers • Coolers • Calciners • Kilns

"Builders of Equipment for People You Know"

Important



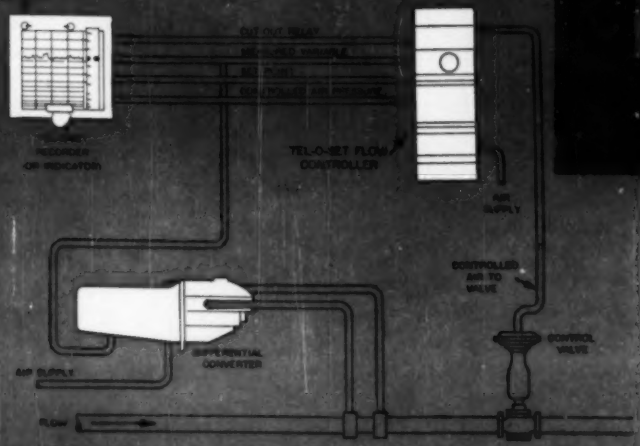


TEL-O-SET CONTROLLER

Available in adjustable and fixed proportional band models, and with three control forms . . . for flow, temperature, pressure, level and other process variables. Universal bracket permits optimum flexibility in mounting . . . coded, interchangeable sections and split manifold contribute to simplified maintenance. Write for Specification Sheet No. 768.

TEL-O-SET RECORDER

Features withdrawal of chassis for full 8-hour chart visibility without interrupting operations, bumpless shifting from automatic to manual operation, all adjustments from front of panel, built-in adjustable restrictions for pulsating flow . . . requires panel space just $5\frac{1}{16}$" high by 5" wide. Write for Specification Sheet No. 769.



TYPICAL ENGINEERED TEL-O-SET CONTROL SYSTEM—Pictured in this diagram are the elements of the *Tel-O-Set* Family, designed and built as an integrated loop. Here the system is applied to the control of flow with the Differential Converter used as transmitter.

TEL-O-SET INDICATOR

Can be used with any pneumatic transmitter, having a 3-15 psi controlled air output, regardless of the primary element being used. Provides indication of process variable, set-point of controller or controlled air pressure to valve when on automatic control . . . is easily shifted to manual operation. Panel cut-out size same as recorder. Write for Specification Sheet No. 770.

Contribution to Process Control

. . . THE HONEYWELL TEL-O-SET FAMILY

THIS pace-setting pneumatic control system is ready for application to a host of processes demanding a new high in speed, precision and accuracy . . . for almost any process variable. Developed as part of a family relationship, each unit complements the others in producing a system of superior performance.

Used with any one of a group of Honeywell measuring elements . . . for flow, temperature, pressure, liquid level, etc. . . . the *Tel-O-Set* system is destined to make important contributions to the improvement of process control throughout industry.

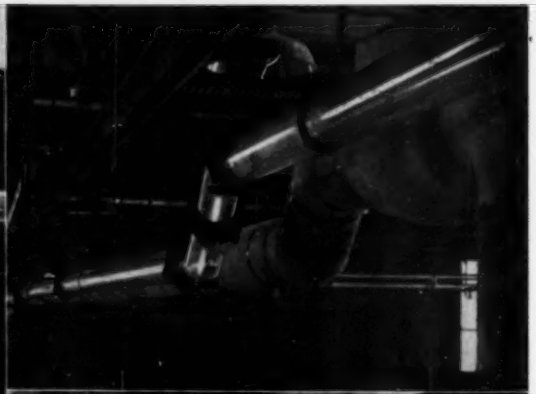
For more detailed information, send for the literature mentioned in the descriptions at left . . . or call in our local engineering representative for a discussion of your process control problems.

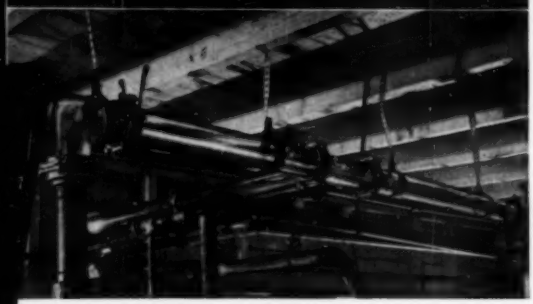
MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4427 Wayne Ave., Philadelphia 44, Pa.

MINNEAPOLIS **Honeywell**

BROWN INSTRUMENTS

First in Controls





Avoid product contamination

...Handle corrosive fluids with safety and economy

use PYREX® "DOUBLE-TOUGH" brand

PYREX brand Glass Pipe is chemically stable, corrosion and heat resistant, transparent, strong; and it can be plumbed at your plant

The head of engineering in a plant manufacturing vitamins says:

"We have selected PYREX pipe to avoid contamination of the product and for its corrosion resistance. Also because of its transparency. In our extraction process, we have to see what's going on.

"We must be particularly careful that no metal particles or salts contaminate our product. Metal is not necessarily recognizable in the product by taste reaction; but it may act as a catalyst, upsetting the chemical reaction which we are producing.

EASY TO INSTALL "When you first go into PYREX piping installations, you may need service from the distributor, but with the proper direction our own men can now handle the equipment very satisfactorily."

NOW STRONGER THAN EVER The new PYREX brand "Double-Tough" Glass Pipe is easy to handle. It's made from heavy-wall machine-drawn tubing. A new heat treating process doubles the strength of the ends of standard flanges and fittings, where applied stresses are greatest. Experience with it will prove that breakage is no problem.

PYREX

CORNING GLASS WORKS, CORNING, N. Y.

Corning means research in Glass

PYREX PIPE IS ECONOMICAL The low first cost, easy installation, and long time corrosion resistance of PYREX pipe combine to make it one of the most economical types of process pipe available.

CONVENIENTLY LOCATED DISTRIBUTORS carry full stocks of all popular sizes of PYREX Brand "Double-Tough" Glass Pipe.

The one nearest you can help you with layouts and installation.

A. J. Eckert Company
Albany 5, New York

Glass Engineering Laboratories
Belmont, California

Macalaster Bicknell Company
Cambridge 39, Massachusetts

Fred S. Hickey, Inc.
Chicago 44, Illinois

Valley Foundry & Machine Works
Fresno 17, California

Sentinel Glass Company
Hatboro, Pennsylvania

W. H. Curtin Company
Houston 7, Texas

Fisher Scientific Company
Pittsburgh, Pa.

Fisher Scientific Company
Montreal 3, Quebec, Canada

Scientific Supplies
Seattle 4, Washington

Stemmerich Supply Inc.
St. Louis 2, Missouri

Mooney Bros. Corp.
Lodi, New Jersey

Will Corporation
Rochester 3, New York

AVAILABILITY PYREX Brand "Double-Tough" Glass Pipe is available in diameters of 1", 1½", 2", 3", 4", and 6" I.D. in standard lengths up to 10 feet. Fittings, including 45° and 90° elbows, tees, reducers, crosses are also available in 1" to 4" sizes. Plug valves are available in 1" and 1½" sizes. *Send for catalog.*

Glass Pipe

"DOUBLE-TOUGH" GLASS PIPE AND FITTINGS are made of the same PYREX brand glass used for PYREX brand laboratory ware. It is corrosion resistant to all chemicals and chemical combinations except hydrofluoric acid, phosphoric acid with traces of fluorides, and hot concentrated alkalis. The following data indicate its high chemical stability and heat resistance:

Loss in weight: 5% HCL for 72 hours at 80° C.—.000002 grams per sq. cm.

Specific heat: 0.20 BTU/lbs. per °F.

Thermal Conductivity: .67 BTU/hr. x ft.^{2} x °F. per ft.

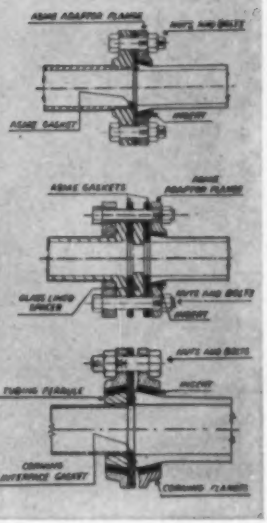
Linear coefficient of expansion: .0000018 per °F. between 32 and 572°F.

Maximum safe operating temperature: 450°F. for piping.

VISIT THE NEW CORNING GLASS CENTER

How to handle PYREX brand Glass Pipe with ease and economy

INSTALLATION IN YOUR PLANT. Pages 10 to 12 of the new PYREX Pipe Installation Manual illustrate step by step the simple operations involved in plumbing PYREX Pipe in the field. Any mechanic or pipe-fitter can handle the usual requirements with a little practice, such as making field flanges or compensating for slight measuring errors or changes in original layouts with adjustable joints or spacers.



HOW TO CONNECT PYREX BRAND GLASS PIPE TO OTHER MATERIALS You'll find it no problem to connect PYREX Pipe to any other standard pipe material, valve, or tank nozzle. For instance, in connecting to standard sanitary metal tubing, you simply braze or silver-solder a stainless steel tubing ferrule to the metal tubing and assemble as described above. See the details on page 9 in the Installation Manual.

PYREX BRAND CASCADE COOLERS are an ideal solution for cooling corrosive chemicals or liquids susceptible to contamination. Special thin-walled tubing with heat treated ends permits maximum heat transfer. These easily assembled, complete units provide low first cost heat exchange plus minimum maintenance. For complete details check coupon below.

CORNING GLASS WORKS, Dept. CEP-3, Corning, N. Y.
Please send me the printed information checked below:

NAME

TITLE

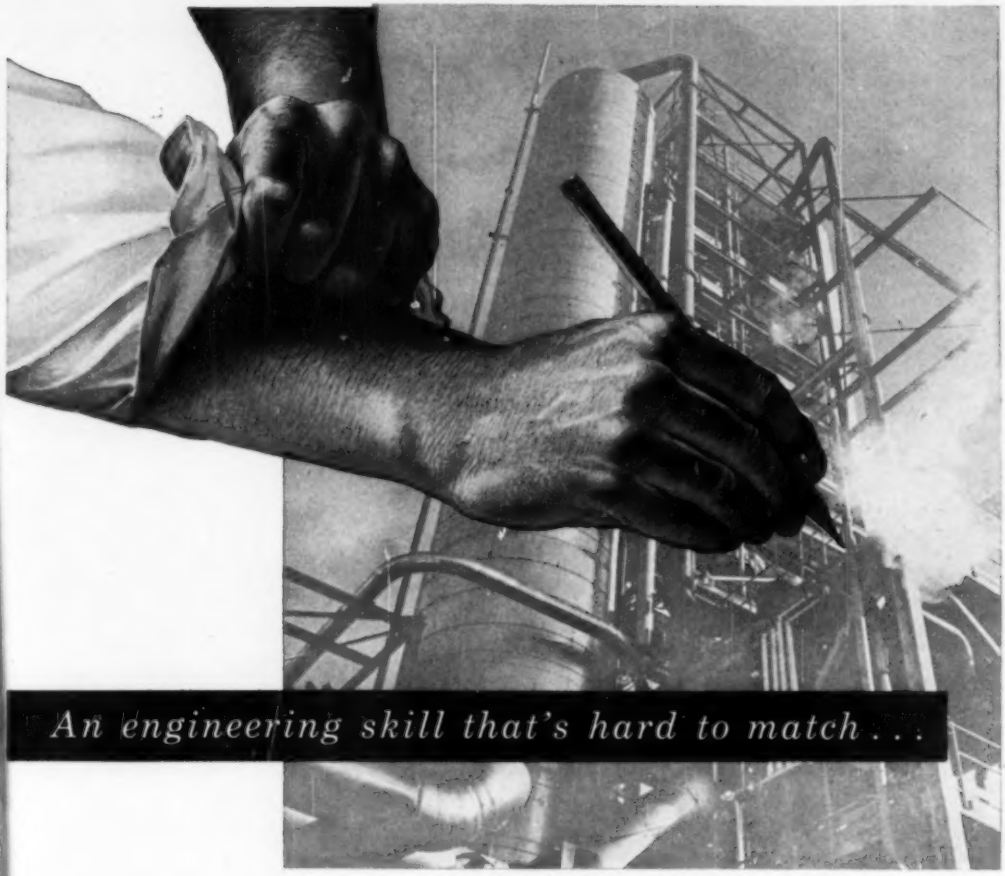
COMPANY

STREET

CITY

ZONE STATE

- ☐ "PYREX brand Glass Pipe in the Process Industries" (EA-1)
- ☐ "PYREX brand "Double-Tough" Glass Pipe and Fittings" (EA-3)
- ☐ "Plant Equipment Glassware for Process Industries" (EB-1)
- ☐ "Installation Manual" for PYREX brand "Double-Tough" Glass Pipe (PE-3)
- ☐ "PYREX Cascade Coolers" (PE-8)



We mean the skill that's acquired after rolling up sleeves 600 times or more—to design and construct that many petroleum refining, petroleum chemical and chemical plants at sites all over the world.

These plants didn't just happen. Lummus men had ideas, practical imagination, the ability to work, a sharp sense of responsibility, and a company policy which placed no limit upon the physical facilities needed to do the job.

All this is worth its weight in gold—an appraisal which our clients express time and again. We see it as a healthy "atmosphere" in which new processes, new techniques, new equipment and new products are developed to our own high standards, and to the satisfaction and profit of our customers.

So we offer this suggestion: put us down as a group with the depth of chemical engineering talent and the breadth of experience to tackle *your* next engineering and construction project —whatever and wherever it may be. And to do it with a skill that's hard to match.

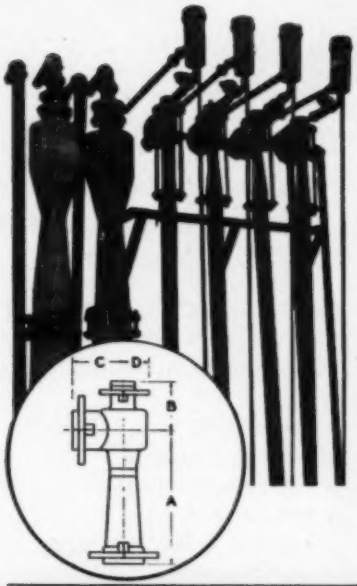
THE LUMMUS COMPANY

385 MADISON AVENUE, NEW YORK 17, N. Y.

HOUSTON • CHICAGO • LONDON • PARIS • CARACAS

DESIGNING ENGINEERS AND CONSTRUCTORS FOR THE PETROLEUM AND CHEMICAL INDUSTRIES

HAVEG



OBNOXIOUS VAPOR SCRUBBER

Connections					
Suction & Discharge	Water Inlet	A	B	C	D
4	1	18"	6 9/16"	6½"	3⅛"
6	2	31½"	12⅞"	11"	5"
8	2	41⅜"	11 5/16"	10⅜"	5⅞"
10	2	46¾"	12¼"	12"	6⅞"
12	2	54¼"	13¼"	13½"	8½"

• Haveg corrosion equipment is molded from a special plastic material into thousands of shapes and sizes. Large tanks and towers, pipes and valves, pump parts, all can and have been made from Haveg by the Haveg Corporation in its Marshallton, Delaware plant using an economical molding method. If you are building for the future you need to know all about this unique corrosion equipment. Since it is not a lining or coating and because it is a solid, molded non-metallic material *Haveg through and through* possesses uniform resistance to corrosion.

CUT COST... RESIST CORROSION

with HAVEG VAPOR CONDENSERS

• One example of the versatility of Haveg is its increasing use for high velocity jet apparatus when used in accordance with established chemical recommendations. The thermal properties of Haveg are such that it is unaffected by rapid temperature changes and will withstand operating temperatures up to 265°F (130°C) without damage.

Operating at low draft and actuated by water pressure, fume scrubbers or obnoxious vapor condensers made of Haveg have proven highly efficient. The throats or diffusers can be made of Haveg in any size and are resistant to wear resulting from high velocity liquids, resistant to the corrosive effects of many gases. Since Haveg can be machined, drilled, threaded, even repaired in the field, all assembly and maintenance is simplified. Also, because Haveg corrosive resistant equipment is molded, a wide range of sizes with individual modifications of the inner dimensions can be produced. Perhaps Haveg vapor condensers can replace for all time some other method you may be using to less advantage for the purging and absorbing of obnoxious gases. Jets, scrubbers, eductors, inter-condensers, all made of Haveg, may help you further cut costs, resist corrosion.

Two Stage S. K. Vacuum Pump with Intercondenser

• A small part of the Haveg Story ... Vapor condensers may not be your problem of the moment, but Haveg should be your corrosion resistant material for the future. Write today for factual, 64-page Bulletin F-6 showing chemical resistance of Haveg, physical properties, design principles, machining, alterations and repair. This technical treatise is of lasting value if you must fight corrosion in your work. Write now! Or call your Haveg district sales engineer.

HAVEG CORPORATION
NEWARK 99, DELAWARE
FACTORY • MARSHALLTON, DELAWARE • TEL. WILMINGTON 3-8884

CLEVELAND 14 — 550 Leader Bldg. — Cherry 1-7297
CHICAGO 11 — 1201 Palmolive Bldg. — Delaware 7-5266
DETROIT 35 — 19951 James Couzens Hghwy. — Broadway 3-0880
CHATTANOOGA 2 — 825 Chestnut St. — Tel. 7-7478
HARTFORD 5 — 86 Farmington Ave. — Hartford 6-4250
HOUSTON 4 — 4101 San Jacinto — Jackson 6840
LOS ANGELES 14 — 523 W. Sixth St. — Mutual 1105
SEATTLE 7 — 5600 14th Ave. N.W. — Hemlock 1351

Over 95%

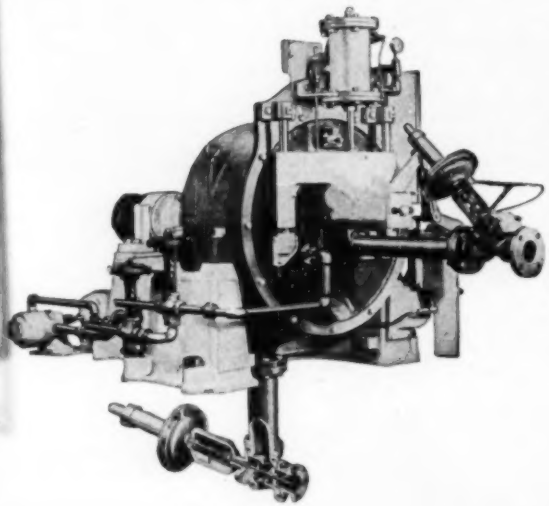
OF THE AUTOMATIC

CRYSTAL DRYING CENTRIFUGES

PURCHASED IN THE UNITED STATES

in 1951 WERE

Sharples Super-D-Hydrators



Bulletin 1257 will be sent upon request.
May we discuss your crystal drying problems with you?

TYPICAL MATERIALS ECONOMICALLY DEHYDRATED WITH THE SHARPLES SUPER-D-HYDRATOR

- ACETYLSALICYLIC ACID
- AMMONIUM PERSULPHATE
- AMMONIUM SULPHATE
- BORAX
- BORIC ACID
- COPPER SULPHATE
- FERROUS SULPHATE
- HEXAMINE
- MONOCHLORACETIC ACID
- NAPHTHALENE
- PARADICHLOROBENZENE
- POLYSTYRENE
- POTASSIUM CHLORIDE
- SODIUM BICARBONATE
- SODIUM CARBONATE
- SODIUM CHLORATE
- SODIUM CHLORIDE
- SODIUM HYDROSULPHITE
- SODIUM SESQUICARBONATE
- SODIUM SULPHATE
- UREA
- ZINC SULPHATE

AND MANY OTHERS

SHARPLES

THE SHARPLES CORPORATION • 2300 WESTMORELAND STREET, PHILADELPHIA 40, PENNA.

NEW YORK • BOSTON • PITTSBURGH • CLEVELAND • DETROIT • CHICAGO • NEW ORLEANS • SEATTLE • LOS ANGELES • SAN FRANCISCO • HOUSTON

LIFE SAVING

ANTIBIOTICS

BY Pfizer

FLOW THROUGH

STAINLESS STEEL

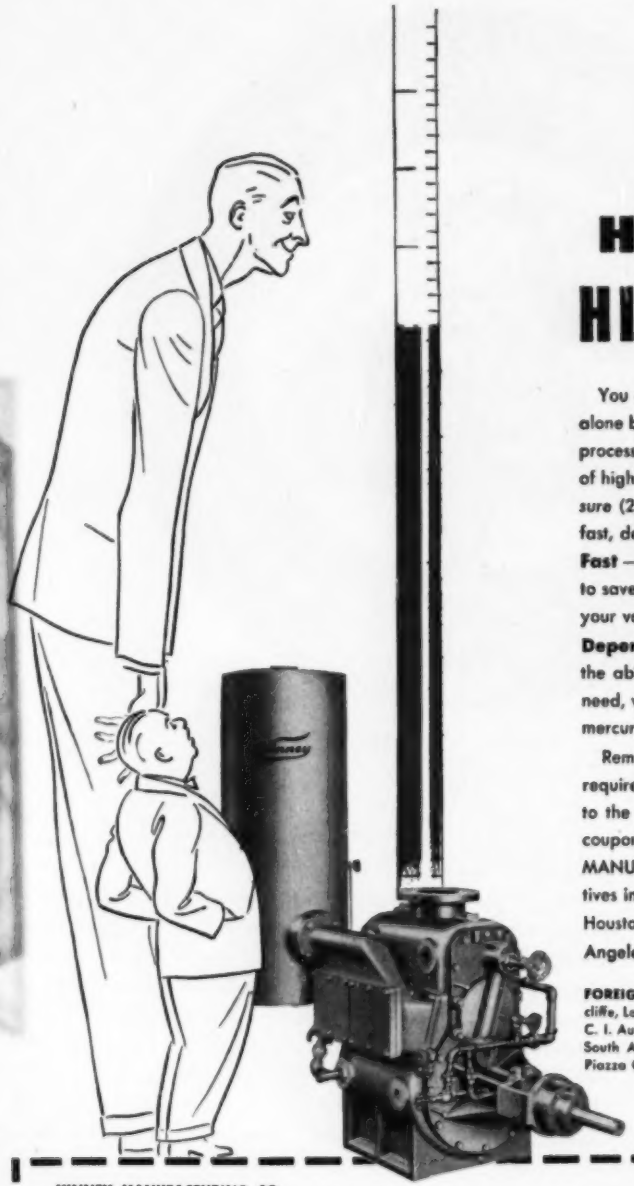
VALVES & FITTINGS

● This man will live—thanks to such "miracle" drugs as terramycin, streptomycin and penicillin. The world over, the balance between life and death hangs on their availability and purity. No one knows this better than the men and women of Chas. Pfizer & Co., Inc.—world's leading producers of antibiotics. That is why Pfizer engineers specify Cooper Alloy stainless steel valves, fittings and accessories for processing units in direct contact with these essential drugs. They know that corrosion resistant metals, cast by Cooper Alloy, mean uninterrupted performance and complete freedom from contamination. Yes, this man will live . . . thanks to medical science, manufacturing integrity, production ingenuity and the reliable performance of stainless alloys.

BY

THE COOPER ALLOY FOUNDRY CO. HILLSIDE NEW JERSEY

Leading Producers of STAINLESS STEEL Valves, Fittings and Castings



How Low is a HIGH VACUUM?

You can't measure a working vacuum by *pressure* alone because *time* also is a big factor in any vacuum processing operation. To provide these two essentials of high vacuum — (1) the *required low absolute pressure* (2) in the *shortest possible time* — is the job for fast, dependable Kinney High Vacuum Pumps.

Fast — Kinney High Vacuum Pumps have the ability to save processing time by speeding up the tempo of your vacuum operations.

Dependable — Kinney High Vacuum Pumps have the ability and stamina to produce the vacuum you need, whether it's measured in fractions of an inch of mercury or fractions of a micron.

Remember, there's a Kinney Pump for every vacuum requirement, from the midget 2 cu. ft. per min. pump to the new giant 1600 cu. ft. per min. model. Send coupon today for new Kinney Bulletin V-51B. KINNEY MANUFACTURING CO., Boston 30, Mass. Representatives in New York, Chicago, Cleveland, Philadelphia, Houston, New Orleans, San Francisco, Seattle, Los Angeles.

FOREIGN REPRESENTATIVES: Gen'l Engineering Co., Ltd., Radcliffe, Lancs., England • Horrocks, Roxburgh Pty., Ltd., Melbourne, C. I. Australia • W. S. Thomas & Taylor Pty., Ltd., Johannesburg, South Africa • Novelectric, Ltd., Zurich, Switzerland • C.I.R.E. Piazza Cavour 25, Rome, Italy.

KINNEY MANUFACTURING CO.
3546 WASHINGTON ST., BOSTON 30, MASS.

Please send new Bulletin V-51B. Our vacuum problem involves:

- ☐ **Vacuum exhausting**
- ☐ **Vacuum dehydration**
- ☐ **Vacuum coating**
- ☐ **Vacuum distillation**
- ☐ **Vacuum metallurgy**
- ☐ **Vacuum research**

Name..... *Company*.....
Address.....
City..... *State*.....

Kinney VACUUM PUMPS

A simple process for the conversion of waste hydrogen sulfide to pure elemental sulfur

The availability of sulfur is rapidly becoming critical to the refining industry. First pinch was evident when sulfur and sulfuric acid were placed under allocation control by National Production Authority.

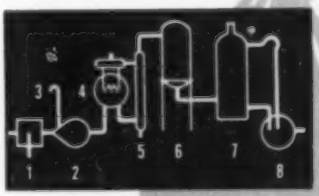
Primary cause of sulfur allocation is a gradual depletion of known deposits. Secondary cause is the great demand for sulfur in the manufacture of vital defense program materials. Mined sulfur is the normal source for such materials. The refiner, however, has in most cases his *own* potential source of sulfur.

Recovery from waste

The refiner's answer is the Mathieson Process for converting into sulfur the waste hydrogen sulfide recovered from sour petroleum gases. This simple process—available through The Fluor Corporation, Ltd.—accomplishes *two* important purposes:

1. *Guarantees independent supply* by affording each refiner an independent sulfur supply to meet his particular requirements—protection for the present, additional income for the future.

2. *Conserves for national defense* by contributing to the over-all National Defense Program in helping to conserve a critical commodity.



THE MATHIESON SULFUR RECOVERY PROCESS Hydrogen sulfide, recovered from a sour gas stream, is partially burned with air—cooling follows with steam generated being utilized for power. Combustion gases are then passed through a catalyst tower to form sulfur and water vapor. Elemental sulfur product is condensed in a wash tower by direct contact with cooled liquid sulfur. The result is pure commercial sulfur—ready for sale or for conversion into sulfuric acid.

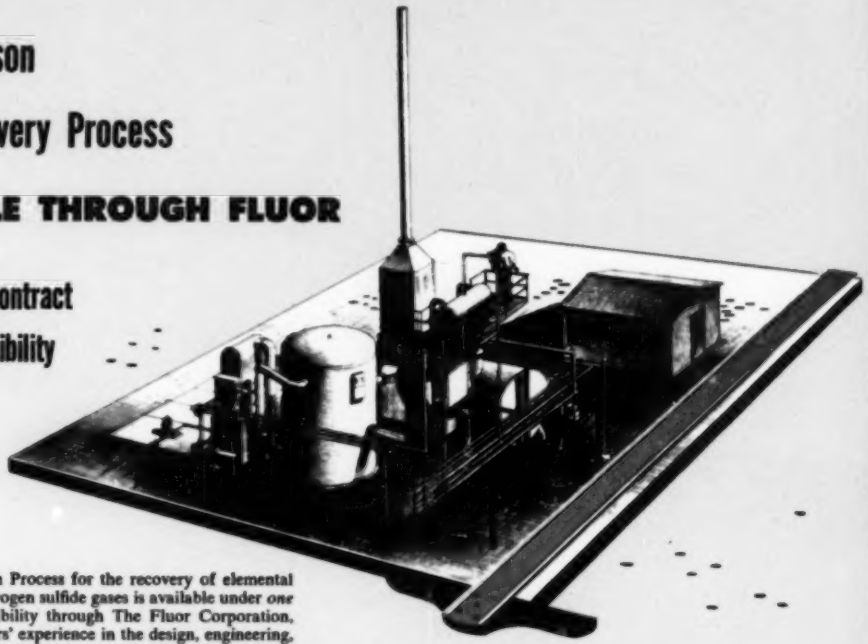
1—TREATING PLANT, 2—REACTOR FURNACE, 3—AIR INTAKE, 4—WASTE HEAT BOILER, 5—ECONOMIZER, 6—CATALYTIC CONVERTER, 7—SULFUR WASH TOWER, 8—RECIRCULATING SUMP

See Reverse Side

The Mathieson Sulfur Recovery Process

AVAILABLE THROUGH FLUOR

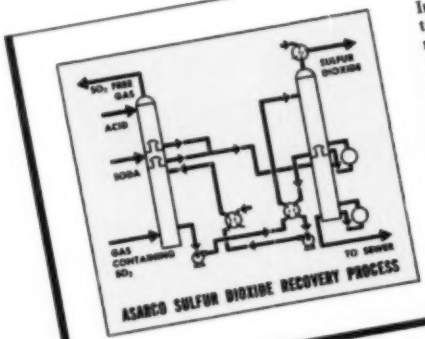
- Under ONE Contract
- ONE Responsibility



The proven Mathieson Process for the recovery of elemental sulfur from waste hydrogen sulfide gases is available under *one* contract, *one* responsibility through The Fluor Corporation, Ltd. With over 30 years' experience in the design, engineering, and construction of plants and facilities for the petroleum and chemical industries, Fluor possesses the background, the skilled personnel, and the know-how essential for the practical interpretation of the Mathieson Process into *your particular* sulfur recovery program.

Fluor is in a position to make economic studies covering every phase of proposed sulfur recovery installations—initial investment, operating costs, and returns to the investor.

A process for the recovery of Sulfur Dioxide is also available through FLUOR



ASARCO SULFUR DIOXIDE RECOVERY PROCESS

In line with Fluor's expanding activity in the fields of gas treating and sulfur recovery, arrangements have been made with the American Smelting and Refining Company (ASARCO) for Fluor to design, engineer and construct sulfur dioxide recovery plants using the ASARCO Process. Fluor's investigations have shown this process to be the most suitable of any available for the removal and recovery of pure sulfur dioxide from stack gases. In the application of the process, the gas is scrubbed with dimethylaniline which is then fed to a stripping column for sulfur dioxide recovery in a cyclic process. The resulting sulfur dioxide product may be dehydrated and liquefied for sale as liquid SO_2 or fed directly to an acid or sulfur plant.

All details including first studies are available through The Fluor Corporation, Ltd., and the American Smelting and Refining Company.

BE SURE WITH **FLUOR**

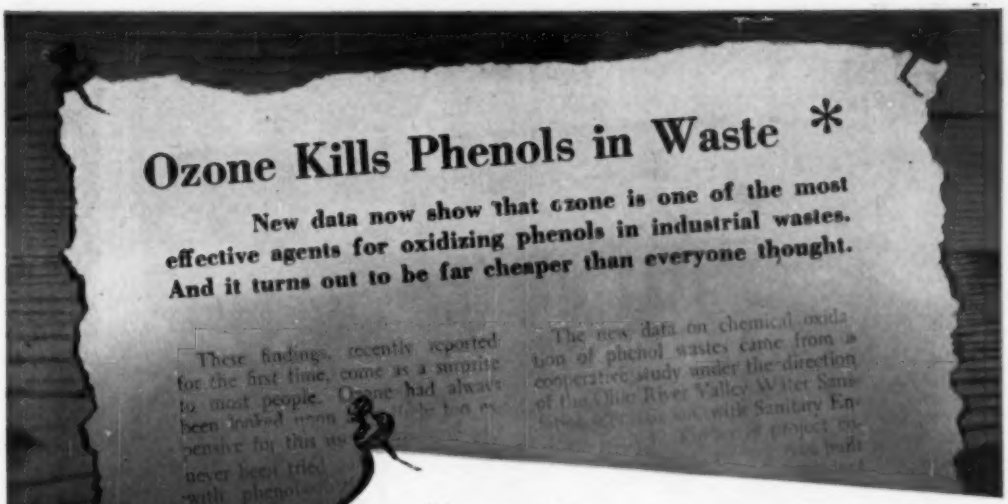
THE FLUOR CORPORATION, LTD., 2500 S. Atlantic Blvd., Los Angeles 22, Calif.

New York, Chicago, Boston, Pittsburgh, Tulsa, Houston, San Francisco, Birmingham, Calgary.

REPRESENTED IN THE STERLING AREAS BY: Head Wrightson Processes Ltd., Teesdale House, Baltic Street, London, E.C.1., England

Ozone Kills Phenols in Waste *

New data now show that ozone is one of the most effective agents for oxidizing phenols in industrial wastes. And it turns out to be far cheaper than everyone thought.



If the presence of phenolic compounds in industrial wastes is a problem to you and your community, low-cost, efficient Welsbach Ozone can be the solution to that problem . . . as proved by the investigations directed by the Ohio River Valley Water Sanitation Commission.

In addition to its low cost, Welsbach Ozone offers dependable, automatic chemical oxidation which requires no full time supervision or labor. With the oxidant being generated at the point of use, there are no procurement, storage or handling problems. *And* . . . operating costs are constant and predictable—a most important advantage with chemical costs going up and up, every day.

The record—as shown by the findings of the Commission—proves that Welsbach Ozone should be the oxidant of choice in solving your phenol problem. Welsbach's "know-how" . . . based on years of pioneering in continuing ozone research . . . is at your service. Write or phone for further information.

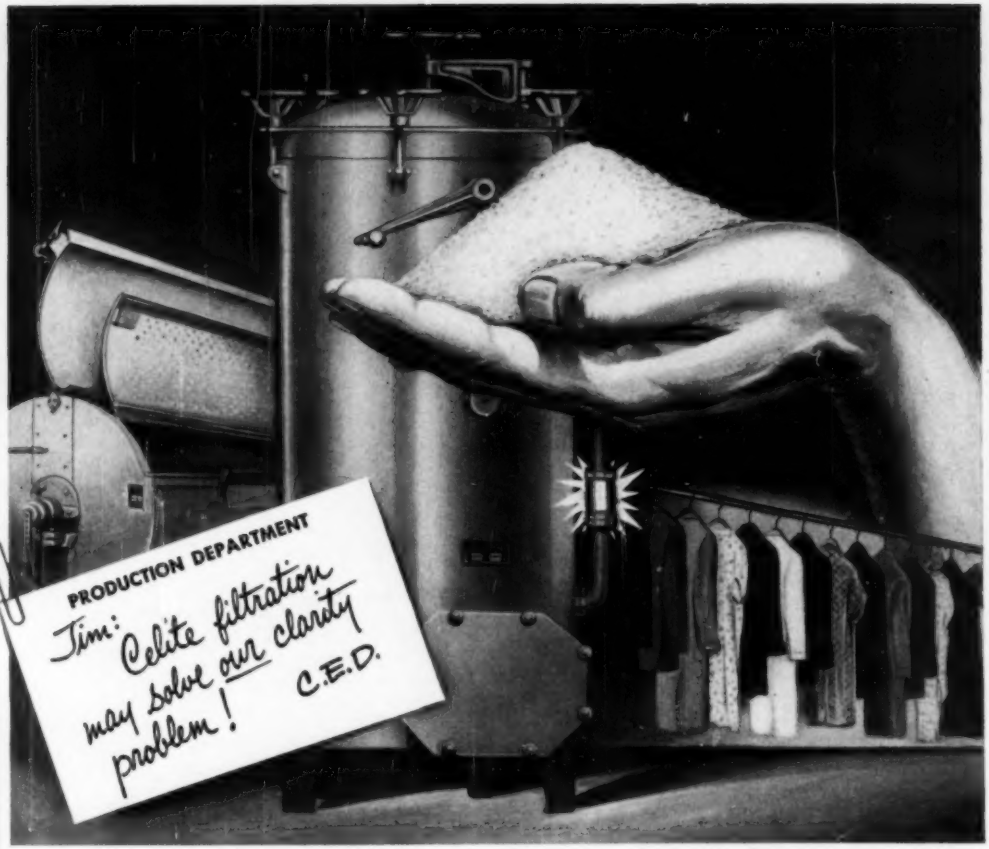
* *Ozone Kills Phenols in Waste, Chemical Engineering, Vol. 58, No. 9, September, 1951. (Complete reprints of this article are available.)*

Write for information on

WELSBACH OZONE

THE WELSBACH CORPORATION
OZONE PROCESSES DIVISION

Pioneers in Continuing Ozone Research



"Drycleaners' Rx" for filtering solvent crystal-clear

MODERN drycleaning plants have discovered that the prescription for keeping their cleaning fluid crystal-clear . . . *an absolute necessity if garments are to be thoroughly cleaned* . . . is Celite* filtration.

The effectiveness of Celite can be attributed to these important factors which make it unique among filter aids:

Carefully processed from the purest deposit of diatomaceous silica known, Celite is available in nine standard grades—each designed to trap suspended impurities of a given size and type. Whenever you reorder, you are assured of the same uniform, accurately graded powder received in your initial order. Thus, with Celite, you can count on consistent clarity and purity in your filtrates—at highest rate of flow—month after month, year after year.

Drycleaning solvent is just one of many liquids for which Celite has provided the absolute clarity vital to a successful operation. The proper grade of Johns-Manville filter aid will assure you the same results—regardless of the product or process involved. To have a Celite Filtration Engineer study your problem and offer recommendations, simply write Johns-Manville, Box 290, New York 16, New York. No cost or obligation.

*Reg. U. S. Pat. Off.

JM PRODUCTS

Johns-Manville CELITE

FILTER AIDS

S-A REDLER Conveyors deliver cellulose acetate from the bottom of a silo to other silos or to processing at the Kingsport Tennessee plant of The Tennessee Eastman Company. An operator is shown taking a sample of material from one of the completely enclosed REDLER Conveyors. An S-A Circular Bin Discharger is also shown below the silo.

S-A CONVEYING Systems for AUTOMATIC STORAGE and delivery of chemicals without CONTAMINATION

REDLER Conveyor-Elevators
ZIPPER Conveyor-Elevators
"Natural Frequency" Vibrating Conveyors
Belt Conveyors
Belt Trippers
Screw Conveyors
Bucket Elevators
Pan Conveyors
Belt, Pan & Plate Feeders
Circular Bin Dischargers
Flight & Chain Conveyors
Centrifugal Loaders & Pilers
Vibrating Screens
TELLEVEL Bin Level Controls
Ship Loaders & Unloaders
Crushers, Roll & Ring Type
Car Pullers & Spotters
Power Transmission Machinery
Hoists & Winches
Storage & Reclaiming Systems
Bin Gates, All Types

Write for Bulletins on any of the above

Each new handling problem presents a different and often unusual set of conditions. Yet, after study, S-A engineers frequently find that a similar problem has been met and overcome on some previous installation. It is from the drafting board of experience that many of the most important S-A bulk handling developments have been contributed to the chemical industries.

It is the S-A engineer's every job to adapt handling methods and equipment to specific situations. For a low-cost-per-ton solution to your particular conveying problems ask an S-A engineer for a recommendation . . . there is no obligation, of course.

STEPHEN S-A DAMSON MFG. CO.

57 Ridgeway Avenue, Aurora, Illinois — Los Angeles, Calif., Belleville, Ontario

DESIGNERS AND MANUFACTURERS OF ALL TYPES OF BULK MATERIALS HANDLING EQUIPMENT

SPEED ADVANCEMENT

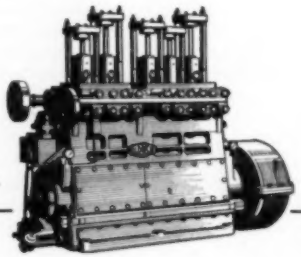
Aldrich did it with Direct Flow Pumps

Not too long ago, 150 rpm was considered high speed operation for reciprocating pumps. But today—as a result of improved design and stronger metals—Aldrich Direct Flow Pumps are operating efficiently at *or over* speeds of 500 rpm for the 3″, 360 rpm for the 5″, and 300 rpm for the 6″ stroke unit. This increase in speed means simply this:

You get more work—greater pressure and volume—out of a smaller pump. You invest in a lighter, lower cost unit . . . a pump with a *sectionalized* fluid-end that's extremely easy to maintain and which can be made of stainless steel, bronze, Monel or other special material, as desired.

Applications include handling of caustic solutions, fatty acids, nitric acid, acetic acid, aqua ammonia, anhydrous ammonia, also liquids encountered in petroleum refining, petro-chemical and other industries.

Request Data Sheets on 3″, 5″, or 6″ Stroke Pumps for complete information.



THE ALDRICH PUMP COMPANY

20 GORDON STREET • ALLENTOWN, PENNSYLVANIA

...Originators of the Direct Flow Pump

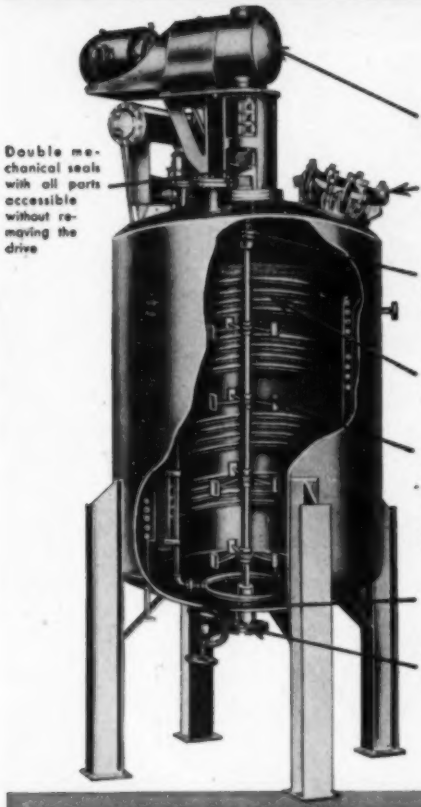
Representatives: Birmingham • Bolivar, N. Y. • Boston • Buffalo • Chicago • Cincinnati • Cleveland • Denver • Detroit
Duluth • Houston • Jacksonville • Los Angeles • New York • Omaha • Philadelphia • Pittsburgh • Portland, Ore.
Richmond, Va. • St. Louis • San Francisco • Seattle • Spokane, Wash. • Syracuse • Tulsa • Export Dept.: 751 Drexel Building, Phila. 6, Pa.

NOW!

The Struthers Wells Hydrogenator

featuring

Advanced Agitator Design for Quick and Thorough Dispersion of Gases and Solids


Standard make right angle motoreducer
Double mechanical seals with all parts accessible without removing the drive
Manhole with hinged cover
Semi-flexible coupling protects drive equipment and pressure seals
Cooling and heating coils
Removable arm radial propeller agitator, giving excellent shearing action and rapid overturning of the liquor, self cleaning in operation
Bottom flush valve
Removable bottom guide bearing

The agitators, supporting structure, agitator shaft seals and drive incorporated in the new Struthers Wells Hydrogenator have been carefully designed to give maximum efficiency and long trouble-free service in dispersing gases and catalysts under normal or extreme conditions of temperature and pressure.

The diagrammatic illustration at the left shows how the agitator shaft is independently supported at two points within the vessel. Note how the radial propeller agitators are mounted in multiple on the shaft dividing the overturning of the content into several strata. The coils are carefully located to provide minimum obstruction to proper agitation and the flush outlet valve eliminates a pocket into which the catalyst might accumulate. This type of equipment is ordinarily made of stainless, nickel, monel, inconel or mild steel and individually designed to operate under specific conditions of pressure, vacuum, temperature and degree of agitation.

RADIAL PROPELLER AGITATOR

Because of its high peripheral blade speed and the rapid overturning and turbulent motion it imparts to the liquor, the radial propeller effectively disperses and entrains both the hydrogen and catalyst within the liquors to be treated thereby creating the optimum condition necessary to a maximum absorption and reaction. The removable arm feature provides inexpensive adjustment of the degree and type of agitation which might be necessary due to change of process or operating conditions.

Write for Complete Data

Struthers Wells

STRUTHERS WELLS CORPORATION

Process Equipment Division ... Warren, Pa.

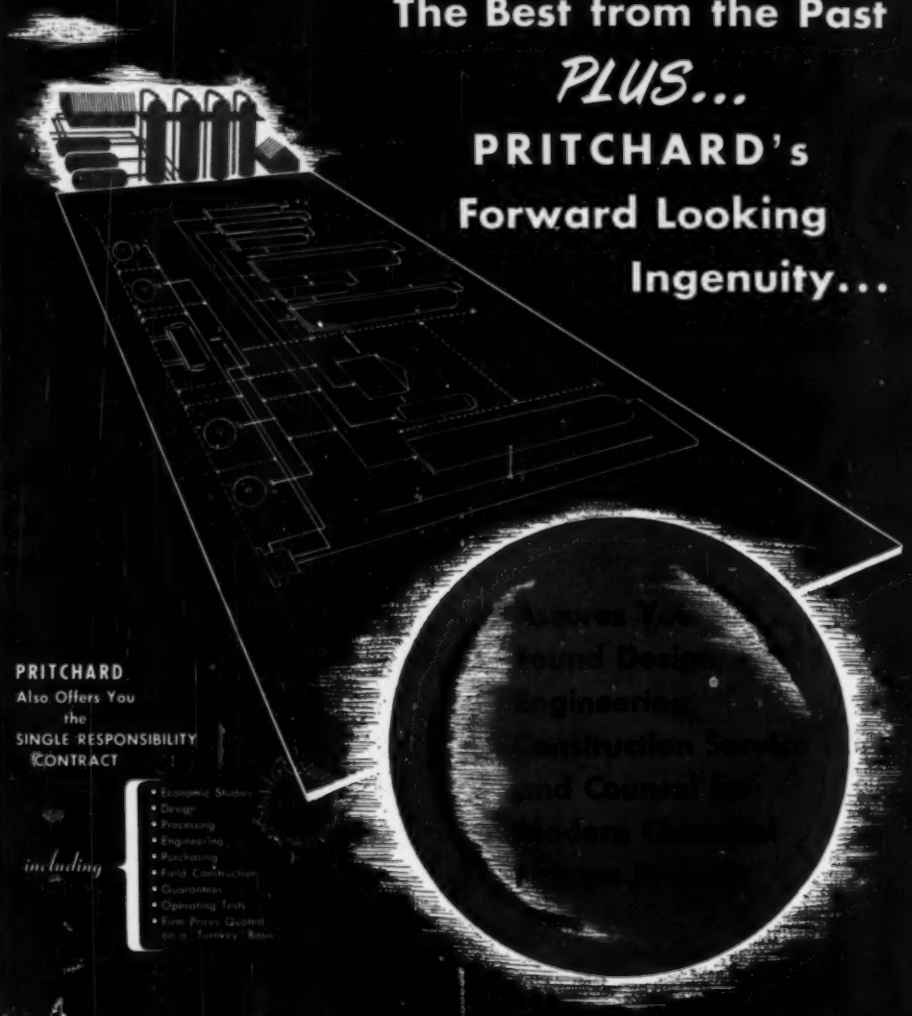
PLANTS AT WARREN, PA. • TITUSVILLE, PA.

Offices in Principal Cities

The Best from the Past

PLUS...

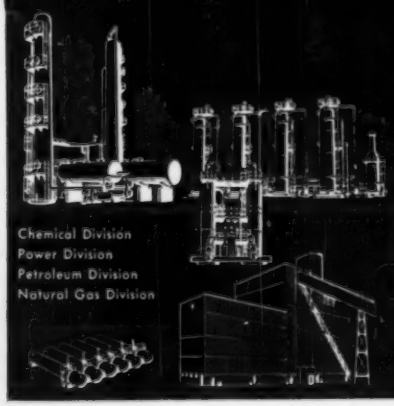
PRITCHARD's Forward Looking Ingenuity...



PRITCHARD
Also Offers You
the
SINGLE RESPONSIBILITY
CONTRACT

including

- Economic Studies
- Design
- Processing
- Engineering
- Purchasing
- Field Construction
- Guarantees
- Operating Tests
- Firm Prices Quoted on a Turnkey Basis



Chemical Division
Power Division
Petroleum Division
Natural Gas Division

Your inquiry is invited.

NATIONAL CONSTRUCTORS ASSOCIATION
MEMBER

J.F. Pritchard & Co.

DESIGN • ENGINEERING • CONSTRUCTION

Dept. No. 249 — 908 Grand Ave., Kansas City 6, Mo.

District Offices: CHICAGO • HOUSTON • NEW YORK • PITTSBURGH
TULSA • ST. LOUIS • Representatives in Principal Cities from Coast to Coast

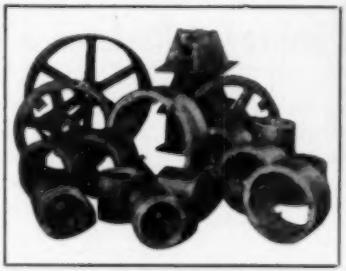
NI-RESIST® CASTINGS PRODUCED IN ALL IMPORTANT INDUSTRIAL AREAS...

Your Complimentary Copy of "Engineering Properties and Applications of Ni-Resist" is Ready at the Nearest Authorized Ni-Resist Foundry Listed . . . Write for It Now.

Abrasive Alloy Castings Co., Bridgeboro, N. J.
American Brake Shoe Co., New York 17, N. Y.
American Brake Shoe Co., Electro-Alloys Division, Elyria, Ohio
American Brake Shoe Co., Engineered Castings Division, Rochester 11, N. Y.
American Cast Iron Pipe Co., Birmingham 2, Ala.
American Chain & Cable Co., Inc., Reading Steel Casting Division, Reading, Pa.
Baker Perkins, Inc., Saginaw, Michigan
Baldwin-Lima-Hamilton Corp., Eddystone Division, Philadelphia 42, Pa.
Barnett Foundry Co., Irvington, N. J.
Buffalo Stainless Casting Corp., Buffalo 11, N. Y.
Carondelet Foundry Co., St. Louis 10, Mo.
Centrifugal Casting Co., Long Beach 7, Calif.
Chicago Hardware Fdry. Co., The N. Chicago, Illinois
Chris. Erhart Fdry. & Mach. Co., The Cincinnati 3, Ohio
Demeron Metal Sales Co., Compton, Calif.
DeZurik Shower Co., Fdry. Div., Sartell, Minn.
Duluth Brass Works Co., Duluth, Minn.
Duriron Co., Inc., The, Dayton 1, Ohio
Eagle Foundry Co., Seattle 4, Wash.
Electric Steel Foundry Co., Portland 10, Ore.
Elizabeth Street Foundry Co., Chicago 36, Ill.
Engineering Castings, Inc., Marshall, Michigan
Fahralloy Co., The, Harvey, Ill.
Frank Foundries Corp., Moline, Ill.
General Metals Corp., Oakland 3, Calif.
Golden's Foundry & Mach. Co., Columbus, Ga.
Hamilton Foundry & Mach. Co., Hamilton, Ohio
Hunt-Spiller Manufacturing Corp., South Boston 27, Mass.
Jenney Cylinder Co., Philadelphia 36, Pa.
Kingsport Foundry & Mfg. Corp., Kingsport, Tenn.
Koppers Co., Inc., Metal Products Division Baltimore 3, Md.
Kutztown Foundry & Machine Corp., Kutztown, Pa.
Michiana Products Corp., Michigan City, Ind.
Michigan Steel Casting Co., Detroit 7, Mich.
Montague Machine Co., Turners Falls, Mass.
Huron Flexible Joint Co., Inc., Louisville 2, Ky.
Olney Foundry, Lick-Bolt Co., Philadelphia 20, Pa.
Pacific Foundry Company, Ltd., San Francisco 10, Cal.
Peru Foundry Company, Peru, Indiana
Posey & Jones Corp., The, Wilmington 99, Del.
Reda Pump Co., Bartlesville, Okla.
Richmond Foundry & Mfg. Co., Inc., The Richmond 20, Va.
Ross-Meehan Foundries, Chattanooga 1, Tenn.
St. Paul Foundry & Mfg. Co., St. Paul 3, Minn.
Shenango-Penn Mold Co., Dover, Ohio
Standard Brass & Mfg. Co., Port Arthur, Texas
Stanley Foundries, Huntington Park, Calif.
Sterling Foundry Co., The, Wellington, Ohio
Taylor & Fenn Co., The, Hartford 1, Conn.
Texaloy Foundry Co., San Antonio 3, Texas
Thomas Foundries, Inc., Birmingham 1, Alabama
Trinity Valley Iron & Steel Co., Fort Worth, Texas
W. S. Tyler Co., The, Cleveland 14, Ohio
Weatherly Foundry & Mfg. Co., Weatherly, Pa.
Wells Manufacturing Co., Skokie, Ill.
Westlectric Castings, Inc., E. Los Angeles 22, Calif.
United States Pipe and Foundry Co. Burlington, N. J.
Utility Steel Foundry, Vernon (L. A.), Calif.
Zenith Foundry Co., West Allis 14, Wis.

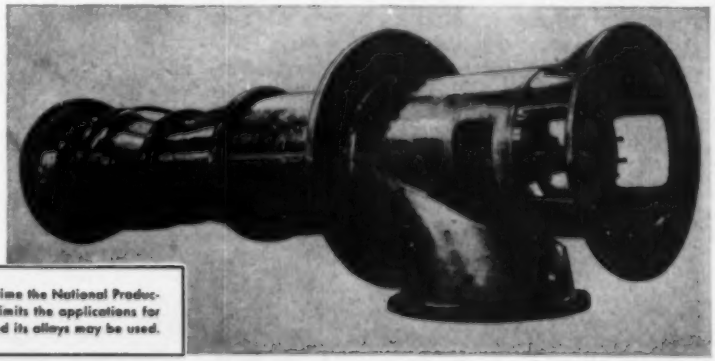
Ni-Resist provides a unique combination of engineering properties: resistance to corrosion, heat and wear; strength and toughness; good machinability; high electrical resistance and, by suitable choice of nickel content, non-magnetic characteristics and high and low thermal expansion. A few typical instances of the numerous successful applications are shown below.

↑ **Light Castings . . .** These piston rings are produced in Ni-Resist for engines used in corrosive service.



↑ **Medium Castings . . .** Free from tendencies to corrode, comminutor parts cast in Ni-Resist lengthen life of sewage disposal equipment.

↓ **Heavy Castings . . .** Casing, outer column and discharge head of this 14-ton pump are cast in Ni-Resist for resistance to salt water and other corrosive media.

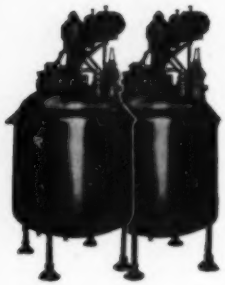


At the present time the National Production Authority limits the applications for which nickel and its alloys may be used.

THE INTERNATIONAL NICKEL COMPANY, INC.

67 WALL STREET
NEW YORK 5, N. Y.

ONE VESSEL does job of two!



NEW PFAUDLER ACID-RESISTING GLASS LINING
Has Improved Resistance to *Alkaline* Solutions

Pfaudler's new acid-resisting glass lining, because of its improved resistance to *alkaline* solutions, gives chemical engineers new freedom to change processes without requiring a change in materials of construction. Dissimilar operations formerly requiring two vessels can now be performed in one.

APPLICATIONS—This new glass should be especially useful in processes involving a neutralization reaction, where the equipment is subjected to alkaline solutions at moderate temperatures for short periods of time. It should be helpful in polymerizers for organic plastics where polymerization is often carried out at a pH of 10 to 12 and at a temperature below 212° F. It may also be used for hot alkaline hypochlorite solutions, where standard glass-lined reactors have been used but with rather short life as compared with that obtained in acid service.

CONDITIONS OF USE—This new glass is intended for use in the pH range from 9 to 12 and at temperatures up to a maximum of 212° F. Within this range of pH and temperature, it has at least 3 times the resistance, and in some cases 10 times the resistance, of any Pfaudler glass formerly available. Users who have applied the new glass in their own plant confirm these results.

To help solve your processing problems, Pfaudler offers a wide range of glass-lined vessels as well as accessories such as pumps, pipe, fittings, and valves. Write now for Bulletin 885, a general catalog describing our products and services.

In a comparative test using buffered NaOH, pH 11.5, at 212° F., the new glass was found to have an estimated life of 12 years compared to 3 years for our present standard glass.

Use GLASS-LINED Steel for:

- Durability
- Corrosion Resistance
- Product Purity
- Easy Cleaning
- Less Product Adherence

Pfaudler

THE PFAUDLER CO., ROCHESTER 3, N. Y.

Engineers and Fabricators of Corrosion-Resistant Process Equipment

THE PFAUDLER CO., DEPT. CEP 3, ROCHESTER 3, N. Y.
Send Pfaudler Bulletin 885.

Name_____

Title_____

Company_____

Address_____

City_____ Zone____ State_____

OPINION AND COMMENT

SINCERITY AND INTEGRITY IN PROFESSIONAL RELATIONS

WE are in troubled times today as so often in the past. Men of national prominence and acknowledged abilities speak for actions and techniques of government which are diametrically opposed. Are they sincere? What is their motivation? We are disillusioned almost daily by those who for personal ambition and power sacrifice ideals, friends, and associates for some personal advantage.

Collegiate sports are justified and promulgated because they can inculcate fair play and devotion to a cause, yet today it seems that this is far from the fact. A college education in engineering is supposed to give a background of facts and the techniques of logic whereby an honest appraisal can be made of the results of their application. How may we assure the desired results in education of men, particularly in the field of engineering?

As one who has long been associated with education, I cannot help but realize the temptations and pressures on young men to find the easy way out, or to seek personal advantage at the expense of others. Industrial management faces similar problems, and the solutions are perhaps more complex. We have become mechanistic in our educational and management programs. We have large classes; industry has large groups of researchers. We regularize tests and reports; it is perhaps necessary to do so, but these are only the mechanistic phases of our professional relations. How can we activate the realization that pride and sincerity of purpose in doing a first-class job should transcend all else in our relations both professionally and personally?

The teacher must strive not only to instill an exact approach and inquiring state of mind to problems of science and living, but also he must make a conscious effort to illustrate thorough and independent work by example. Much that we do with the student may not bear fruit until years later. We are now influencing the *next* technical generation.

What can be done about those now in college or those who have just entered the industrial world? The young men who are project and group leaders can influence the young technical graduate just as college professors can. Perhaps they can be of greater influence, because they set the example of pride in a job thoroughly done at a time when the hopes and expectation of the newcomer are highest. The young technical supervisors have demonstrated some measure of thorough, sincere, and cooperative work or they would not have been placed in supervisory positions. Let them continue in this way with the added realization that those working under them expect some measure of earnest purpose and pride in sound accomplishment. To finish a job with skill and dispatch, particularly in cooperation with others, requires a sincerity of purpose in personal relations and in technical skills. It is relatively easy to teach technical skills by example; we do that in school and in industry. It is a much more difficult task to activate top-quality sincerity in personal relations. I believe the approach to professional living must be made by personal example, and that the future attitudes of technical men are dependent on those in the teaching and industrial fields.

In education we have lost something as our numbers of students have increased. No longer is it easy to develop close relations between student and teacher in undergraduate work. Even in graduate education we have less of the concept of a student studying with a professor—sitting in the laboratory with him—absorbing by contact in a relaxed atmosphere the intellectual fellowship that has always proved stimulating. Rather we tend to pursue a program of study and often minimize the personal association with active-minded teachers.

Years ago industry operated with an apprentice system—quite analogous to the relationship of the professor with student. Those in industry dealing with young men can make up for this personal loss by making a conscious effort to take over the job of the teacher—teaching by example. With attention to the basic ideals of sincerity and integrity of purpose, we do have an opportunity to offset the trends toward careless, indolent technical work. These are not ideas and ideals that are easy to instill, and they often slip away if there is no stimulant to keep them activated. We can and must set high standards for work well done. In doing so we may help to offset the waves of indifference, insincerity, and distortion of thought and fact that seem so common in these times. Pleasure in work is in large part due to the ability to do it well. We come to enjoy putting our best efforts into the job. Are we older professional men fully aware of our responsibility to influence those following us?

J. HENRY RUSHTON

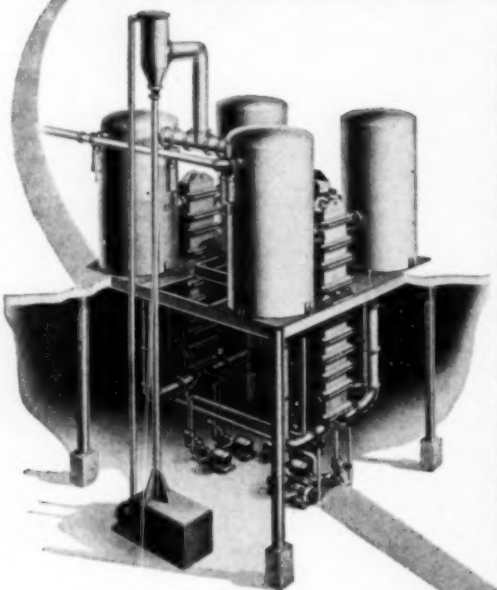
Engineers and Fabricators of Corrosion-Resistant Process Equipment

City_____ Zone____ State_____

Conkey Flat Plate Evaporators with Rosenblad Switching System*

Completely self-cleaning during operation

No down time! No scale removal costs!



Conkey 4-Body Triple Effect Flat Plate Heating Surface Evaporator

Take a leaf from the flow sheets of another industry. For years evaporation of spent sulphite pulp cooking liquors in sulphite pulp manufacture was considered highly impractical because a gypsum coating developed on heating surfaces. But today—it can be a *continuous, full capacity self-cleaning operation* through use of Conkey Evaporators and Rosenblad Channel Switching System.

The advantages of the Rosenblad Channel Switching System have been thoroughly proven both in this country and abroad. Heating surfaces, interconnecting pipe and pump systems *are completely cleaned during normal operation!* It's especially effective wherever lime salts scale evaporators.

Conkey equipment adapts itself well to channel switching for self-cleaning operation while providing all the other advantages of multiple effect evaporation: forced circulation . . . falling film . . . recompression . . . thermal compression . . . high vacuum and other specialized benefits where required.

*Patents Applied For

PROCESS EQUIPMENT DIVISION GENERAL AMERICAN TRADE MARK

PROCESS EQUIPMENT DIVISION
GENERAL AMERICAN
TRANSPORTATION CORPORATION

Sales Offices: 10 East 49th Street, New York 17, New York
General Offices: 135 South LaSalle Street, Chicago 90, Illinois

Sole licensee in the U. S. A. for the
A. B. Rosenblads Patenter Evaporator Switching System.
OFFICES IN ALL PRINCIPAL CITIES

GET THE FULL DETAILS. Write today for new bulletin. See how a Conkey Evaporator with Rosenblad Switching System can eliminate down time, eliminate scale removal costs and keep a constant flow sheet for you.

Other General American Equipment: Turbo-Mixers, Filters, Dewaterers, Dryers, Towers, Tanks, Bins, Pressure Vessels.

DESIGNING FOR MAINTENANCE

L. B. WOOLFENDEN and RICHARD C. THIEDE

General Aniline Works, Grasselli, New Jersey

REGARDLESS of the field of engineering, whether it be the design and erection of structures; of highways and bridges; or whether it be the design and installation of process equipment, there exists, between the design engineer and the engineer responsible for the building and maintaining of structure and equipment, a problem of coordination. Each in his own right has technical problems which must be solved as economically and practically as possible, and each individual applies his best technical knowledge and experience to this solution. Unfortunately, the problems which should be mutual are not thoroughly understood or appreciated by the branches of engineering involved.

There is in today's operation of industry a tendency on the part of process and design engineers to hand off to the maintenance engineer, equipment which the maintenance engineer has had little or no say in selecting. It is tacitly assumed that the maintenance engineer will be able to keep the equipment running and maintain it.

Seldom is maintenance considered of particular importance in the initial design and process layout. The attitude is that the economics of maintenance is a problem for the maintenance engineer alone. He in turn is confronted with increasing labor and material costs and is constantly being asked, "Why do we have to spend so much to maintain the plant?" "Why do we have to take equipment out of service so soon after installation?" "Why did such a small repair cost so much?" or, "What are you going to do to reduce repair cost on equipment?"

The answer, in part, is that some of the problems of maintenance arise from the original design and layout of plant and equipment. Due consideration of maintenance cost should be given by process engineers, and by the design and layout men, long before a foundation is cast or equipment is ordered.

The design engineer has the problem of providing structures and equipment, to serve specific purposes, with a low installed cost and as conservative of space as possible. His concern is that such structure and equipment conform to prescribed building or labor code regulations; that they be strong and suitable for the purpose intended; that, in the case of equipment, shop fabrication be possible on standard machine shop facilities; that such equipment be readily handled and shop assembled; and, as invariably happens, that some provision be made to take care of future expansion. The designer is primarily concerned with first-costs economies.

In making his decisions on equipment, he is guided by the cost, by the availability and delivery, and by company policy; he has to rely largely upon data and operating information furnished by manufacturers' representatives. Usually the designer's interest in maintenance is nominal, and satisfied with mere assurances from the manufacturers' representatives that spare parts are stocked and available. There, as a usual thing, his interest in the matter of maintenance begins and ends.

Too often in the purchase of package items, such as pumps, compressors, evactors, or boilers, the fact is either overlooked or ignored that these units are originally shop assembled. As such, and with the particular unit being accessible from all sides, the time required in assembling or installing any one item of the unit is relatively small as compared to a similar field replacement. Once the unit has been bolted and grouted to a foundation, piped up, electrically connected, fully insulated, surrounded with other equipment, and exposed to operating conditions, the cost of relative minor repairs under these conditions skyrockets out of all proportion to shop conditions. The manufacturers' estimated time to effect replacements is usually based upon shop

L. B. Woolfenden

L. B. Woolfenden became associated with what is now the General Aniline & Film Corp. at Grasselli, N. J., in 1929, and has been there ever since. He worked as designer, inspector, field engineer, assistant plant engineer, and was made plant engineer in 1944, the position he now holds. He is secretary-treasurer of Plant Engineers Association of Metropolitan New York. Mr. Woolfenden was graduated from M.I.T. in 1927 with a B.S. in chemical engineering.

R. C. Thiede

R. C. Thiede is chief field engineer of the General Aniline Works, also located in Grasselli, N. J. A B.S. graduate of Muhlenberg College, he did post-graduate work at the University of Pennsylvania. Early in his career he was associated with the General Chemical Co. as production supervisor and subsequently served Hungerford & Terry, Inc., as service engineer. He has done considerable work in industrial water treatment. He is a member of the New Jersey Society of Professional Engineers (Associate).

experience and has little bearing on actual field requirements.

In support of this is our experience in the installation, on a plant-wide basis, of close coupled motor pumps. Initially, the use of such units was economically attractive. The first cost was less than that of a coupled pump; they required less floor space and smaller foundations; and a smaller inventory of spare parts was indicated.

We made several installations and placed the pumps in chemical handling service for which their material of construction was suitable. Initially, we were satisfied with pump performance and were fairly well sold on the idea of using motor pump units as a standard practice. As in the case of most centrifugal pumps handling corrosive liquids and chemical slurries, in due time we experienced a drop in performance, and impeller replacements were indicated.

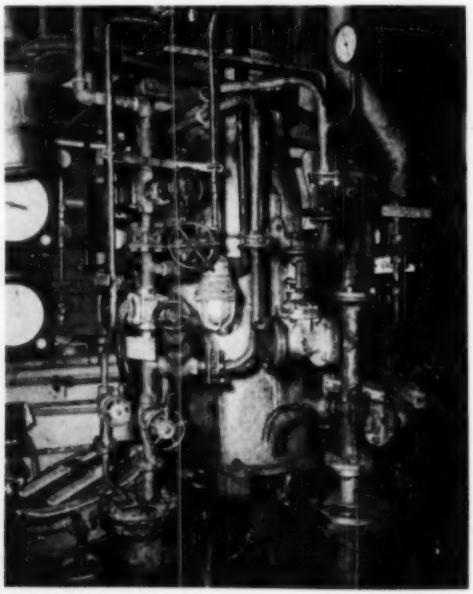
In making repairs, we observed that in every case where in the interest of space conservation we had utilized a high speed motor (3400 rev./min.), impeller wear was severe, and we could expect short impeller life. In some cases, the impeller key and shaft keyway had been chemically attacked and now allowed too much impeller play. Where shaft keyways were not severely damaged, corrosion wear was compensated for in the field by using oversized keys. This meant that the new impeller also required adjustment to fit the oversized key. Where the shaft keyway was severely damaged, we had no choice except to dismantle completely the unit, take it into the shop, remove the motor rotor, press out the integral rotor-impeller shaft, install a new shaft, completely reassemble and reinstall the unit. In most cases, the cost of making this repair equaled or exceeded the original installation cost.

A similar repair to a coupled shaft pump could have been made by simply uncoupling the impeller shaft and installing a new shaft, an operation requiring less down time and costing approximately one-fourth the number of man-hours.

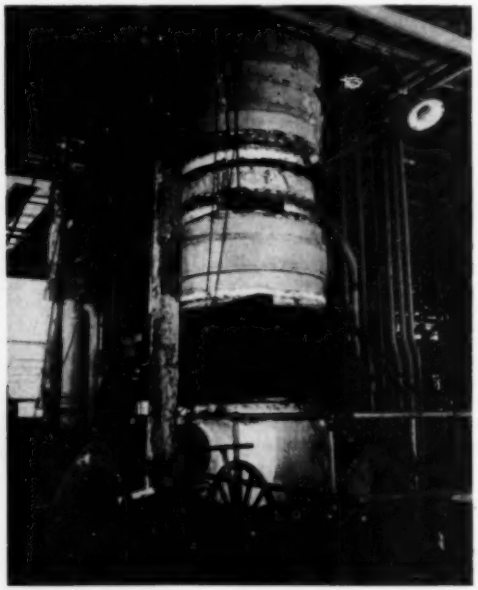
The maintenance situation on motor pumps was further complicated by the fact that the pumps were tailored to the designer's performance specifications and used drive motors from 1 to 10 hp. in size. This required a large inventory of spare shafts to insure adequate maintenance coverage. Further to complicate the maintenance engineer's problems when such repairs as outlined above occur, a temporary pump installation is usually required for production requirements.

In light of our maintenance problems, we now specify in original design, coupled shaft pumps for corrosive chemical handling, and limit motor speeds to 1800 rev./min. We specify open-type impellers since they have proven less troublesome to us than the closed-type. I do not imply that we do not use motor pumps. We are still interested in the initial cost and installation economies, but we limit their use to the less corrosive services, such as recirculating tower water, treated refrigerated brines, alcohols, etc., or to such installations where temporary loss of service does not seriously affect production cycles.

The maintenance engineer necessarily works closer with the production department using the installations, and is the first to receive the criticism of all the major and minor equipment faults coming to light under actual operations. The personal whims of operators are dropped into the maintenance engineer's lap, and he is expected to do something about it. As, for example, valve hand wheels which are inconveniently located for ease of operation; or the manhole cover which is a little too heavy and should be counterweighted; or the relocation of an overhead light which cast a shadow across the face of a temperature recorder. To his attention are also called the little nooks and crannies in the building structure which plague those inter-



Closely compacted piping installation provides ready access to valves and facilitates production operations of this reaction pressure vessel, but maintenance or repairs of centrally located agitator drive necessitate costly piping dismantling operations.



Dismantling of this 5-ft. diam. bubble tower for cleaning purposes required costly rigging operations in this closely confined installation. In addition to work actually required on the tower, it became necessary to dismantle existing piping and to dismantle partially neighboring units to provide rigging space requirements.

ested in good housekeeping, and he is asked why floor drains were not located so that the trucks used in production material handling wouldn't be required to bump over them. All these might be considered minor in nature because in themselves they do not affect the original intent or purpose of the building or equipment. But, once having been called to attention, it becomes obvious that they could have been prevented initially. Correction after installation increases repair and maintenance expenditures.

When major dismantling of equipment becomes necessary, the maintenance man suddenly finds that what fitted so nicely together when new now requires considerable man-hours of time to take apart. The bolts that fitted snugly through equipment flanges when new have corroded fast, and now must be cut or drilled out at considerable expense. The tubular condenser that was fitted into an odd corner in the designer's effort to conserve space can neither be cleaned adequately nor repaired without a major dismantling operation.

In the case of bolts, a more corrosive-resistant material, if available and suitable, might have reduced dismantling expenses; or, barring the possible availability of such material, a fraction of an inch more clearance in design would have prevented the problem. In the case of the condenser, it might be argued that the initial economy effected by the conservation of space, as compared to the normally anticipated dismantling requirements, justified the condenser location. While this may be so, one cannot lose sight of the fact that once equipment is in service, down time for repair is also lost time from production. Likewise, the responsibility of holding to minimum repair costs, which are ultimately reflected in production cost, is the problem of the maintenance engineer, more acutely so than it is that of the designer.

Unfortunately, the maintenance engineer is likely to accept these difficulties as part of his job, and proceeds to make alterations and corrections without calling such faults to the attention of the process and design engineers.

In our organization, we have found that setting up standards for equipment has been helpful in coordinating design and field work. Having once set such standards, any feature originally embodied and later coming to light as undesirable can be corrected to prevent recurrence. Such standards offer additional desirable features of interchangeability of essential parts, reduced spare parts inventories, and lower design and maintenance costs.

However, it is not at all possible to avoid the purchase and installation of special units designed for a specific operation. Something new is always being developed and added. At times these specials prove quite costly to install, and the question might well be raised as to why new equipment, designed for a specific job, requires a substantial outlay to get it to perform. A check of expenditures on several units falling into this special equipment classification disclosed that on an initial capital investment of between $10,000-$15,000, as high as 25% of the original investment was required, in the first year of operation, to achieve the desired performance. After this initial expense, the subsequent ten-year average of maintenance cost was 7 to 8% of the original capital investment.

A detailed study of first-year expenditures revealed that relatively minor alterations were required on such items as gear adjustments, alterations to stuffing boxes and glands, extension of grease fittings, and the refinement and incorporation of safety devices. Most of the expense incurred was caused by man-hours required to dismantle equipment in an effort to determine why it was not performing, and in studying operating conditions in order to determine corrective steps.

It is felt that by closer attention to design detail, more careful study of operational requirements, and closer specification in the initial design and installation, the first year's operational expense could have been substantially reduced. This is borne out by the fact that two similar units purchased subsequently and designed and specified to incorporate all the altered features of the first did not require the high initial expenditure.

In the field of materials of construction for the handling of corrosive liquids and solutions, it is highly important that a close cooperation exist between design and maintenance engineers. This is particularly desirable where equipment requires a degree of flexibility in use, and is less important where unit processes exist and where years of experience have established the service life of the materials of construction.

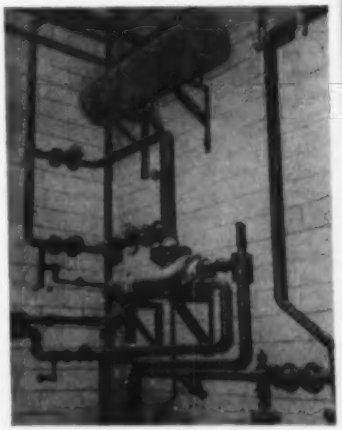
The maintenance engineer, if he is on the job, is constantly trying out new materials such as gaskets, paints, valves, sight-glasses, oils, greases, insulations, pipe hangers, etc. As he finds better materials to do his job, he incorporates new items in field installations and may not always give enough thought to passing on his findings or to setting down on paper the conclusions of his investigations. Often these findings are useful in determining the material of construction for design purposes.

As an example, one of our engineers in charge of maintenance in one area of the plant experienced corrosion problems in steel pipelines handling 100% sulfuric acid. The life of the steel line was approximately two years. The line was used to fill small acid measuring tanks from an overhead storage, and when not in service was shut off and allowed to drain. Moisture entering with the air diluted the residual acid in the line, and when failure occurred it was observed that a very distinct grooving by corrosion at the bottom of the line ultimately resulted in complete failure. The line was renewed in a stainless steel, and for six years has been entirely trouble free. At the time of renewal, the engineer estimated that a life of four years would be required to justify the increased cost of the stainless steel.

Such information is of importance and should be made generally available to all maintenance supervisory personnel.

We have found that it pays to centralize such corrosion studies and have within the department a Corrosion Section, whose duty it is to correlate corrosion information and to issue periodic newsletters informing all plant supervisory personnel of latest developments.

In our attempts to coordinate design and field endeavors, we have found that individual records of all installed equipment, on which are recorded all current changes in design and alterations in materials of construction, are highly essential. In addition, individual folders to accumulate expense charges have proven most helpful in checking back on type and nature of repairs and frequency of recurrence.



Installations crowded into odd corners in the interest of space conservation later result in poor painting maintenance, costly piping dismantling to permit routine pressure testing or to permit heat-exchanger tube replacements.

GENERALIZED GRAPHICAL METHOD FOR THE DESIGN OF FIXED BED CATALYTIC REACTORS

THOMAS BARON †

University of Illinois, Urbana, Illinois

A graphical method is developed for the design of fixed bed catalytic reactors. This method, based on a consideration of the lateral heat and mass transfer occurring in the bed, is useful for all heat-transfer situations provided some simple symmetry, e.g., cylindrical symmetry, may be assumed. Equations are derived from statistical considerations for the effective lateral diffusivity of heat and mass. These equations are consistent with experimental data reported in the present work, as well as with data presented by Bernard and Wilhelm, and Singer and Wilhelm. The theory, as well as the data indicates that, provided the catalyst pellets have low thermal conductivity, the effective diffusivity for mass transfer is numerically equal to the effective diffusivity for heat transfer. It is also shown that when the total number of moles passing through the reactor is essentially constant, the reactants and products at any point are always present in stoichiometric amounts. This result, as well as the identity of effective diffusivities for heat and mass allows a simple graphical design, which yields the distribution of temperature and fractional conversion. The design is based on rate data, obtainable from differential reactors, giving the reaction rate in terms of the temperature and the fractional conversion of the limiting reactant.

A METHOD for designing fixed bed catalytic reactors must be based on the physical and chemical processes occurring in the reactor. In any arbitrarily chosen, small volume of the bed, the temperature is determined by a heat balance which involves the diffusion of heat, the heat flux due to flow and the heat generated by chemical reaction. The rate of reaction is a function of the catalyst temperature and the surface concentrations of reactants, products, and inerts, which, in turn, depend on the bulk temperature and concentrations, and the heat- and mass-transfer rates between the fluid and catalyst pellets. Finally, the bulk concentrations are determined by material balances involving lateral diffusion through the bed (as distinguished from diffusion to the catalyst pellets), mass flux due to flow, and chemical reaction.

Experimental data obtained from differential reactors relate the reaction rate to either the catalyst temperature and surface concentrations or to the fluid temperature and bulk concentrations. In the former case, the reaction rate may be related to the bulk conditions by a consideration of the mass and heat transfer between the fluid and the catalyst (*17*). Grossman (*5*) considered the differential equations describing the heat-transfer conditions in the bed and indicated a convenient graphical method of solution. This method, however, does not account for the effect of lateral diffusion of the various components. An appreciation of the importance of lateral diffusion may be obtained by considering an exothermic reaction occurring in a fixed bed cylindrical reactor, cooled at the wall. Due to higher temperatures, the reactants are depleted and the products are produced faster near the center than in regions close to the wall. The result is a lateral diffusion of reactants toward the center, and of the products toward the wall. Thus, the important reaction zone is continuously fed with reactants which keep the reaction going, and is depleted of products which tend to retard the reaction. Neglecting lateral diffusion may therefore result in seriously underestimating the over-all conversion.

In the present work equations which throw considerable light on the mechanism of heat and mass transfer in packed beds are derived for the transport parameters, and a graphical design method is developed which represents an improvement since, (1) lateral diffusion is taken into account, and (2) the equation describing heat transfer is simplified without sacrificing accuracy.

Development of Design Equations

Consider a differential volume of a bed packed with catalyst pellets of negligible thermal conductivity. Then the Fourier-Poisson equations for heat transfer and for the mass transfer of the n chemical species present are:

$$\frac{\partial}{\partial\theta}(C_p\rho t) = -div(-k\ grad\ t) - div(\vec{G}C_p t) + R_t\rho_B\lambda \qquad (1)$$

and

$$\frac{\partial C_i}{\partial\theta} = -div(-D\ grad\ C_i) - div\ \vec{V}C_i - R_i\rho_B;\ i = 1, 2, \ldots n \qquad (2)$$

The terms on the left in Equations (1) and (2) represent the total rate of accumulation, the second, third and fourth terms represent the rates of accumulation due to diffusion, flow and chemical reaction respectively. These equations are based on the fundamental assumption that it is possible to choose the size of differential volume sufficiently large to contain a considerable number of pellets, and at the same time sufficiently small to allow the assumptions of uniformity of temperature and concentrations. It follows that the rate of generation of heat and mass may be assumed to be uniform over the differential volume. While this assumption is to some degree self-contradictory, simi-

† Present address: Shell Development Co., Emeryville, Calif.

lar assumptions in other branches of applied mathematics, notably in turbulence theory, have met with considerable success.

The actual velocity, $\vec{V}$, at any point in the bed may be represented as the vector sum of the superficial velocity $\vec{V}_o$, and a velocity fluctuation $\vec{v}$, characteristic of the point in question. The latter is due mainly to deflection of the fluid by catalyst pellets. Then

$$\vec{V} = \vec{V}_o + \vec{v} \tag{3}$$

Similarly for the actual point concentration,

$$C_i = \overline{C_i} + c_i \tag{4}$$

Here $\overline{C_i}$ is the concentration averaged over the differential volume, while c_i is a concentration fluctuation due to the velocity fluctuations.

Using Equations (3) and (4), Equation (2) may now be expressed in terms of the average and fluctuating quantities. One obtains upon averaging over the differential volume and assuming steady state:

$$-div(-D\ grad\ \overline{C_i}) - div\ \vec{V}_o\overline{C_i} - div\ \overline{\vec{v}\,c_i} - \overline{R}_{\rho B} = 0^* \tag{5}$$

Here the quantity $\overline{\vec{v}\,c_i}$ represents the flux due to the fluctuations caused by the catalyst pellets. The axial component of this flux may be neglected with respect to the much larger axial flux due to the mean flow. The lateral flux may be estimated by methods analogous to those used in the elementary kinetic theory of gases. Consider three parallel planes perpendicular to the lateral direction, the distance between the planes being $\lambda/2$, where λ is a suitable mean free path. Let the central plane be situated at a lateral position r and assume that matter crossing this plane in a positive (or negative) sense originated from the plane at $r - \lambda/2$ (or $r + \lambda/2$). Furthermore, let v_l denote the average of the absolute values of the lateral velocity fluctuations. The flux originating from any plane is proportional to $v_l\overline{C_i}$. Thus, the flux crossing the central plane in the positive sense is proportional to

$$(v_l\overline{C_i})_r - \lambda/2\ grad_l v_l\overline{C_i}$$

where terms of second and higher orders in λ are neglected. Similarly the flux crossing the central plane in the negative sense is proportional to

$$(V_l\overline{C_i})_r + \lambda/2\ grad_l V_l\overline{C_i}$$

Hence, the net flux due to fluctuations is

$$\overline{\vec{v}_l C_i} \propto -\lambda\ grad_l v_l\overline{C_i} \tag{6}$$

or, since v_l is proportional to V_o and assuming that the mean free path is proportional to the pellet diameter

$$\overline{\vec{v}_l C_i} = -Kd\ grad_l V_o\overline{C_i} \tag{7}$$

where K is a constant characteristic of the packing only. The fluctuating quantities may now be eliminated from Equations (5) and (7).

$$-div[-D\ grad_l\overline{C_i} - Kd\ grad_l\ V_o\overline{C_i}]$$

$$- div\ \vec{V}_o\overline{C_i} - \overline{R}_{\rho B} = 0 \tag{8}$$

Consider the case of mass transfer without chemical reactions under isothermal conditions. Then, since V_o is a constant, Equation (8) becomes

$$-div - [(D + KV_o d)grad_l\overline{C_i}]$$

$$- div\ \vec{V}_o\overline{C_i} = 0 \tag{9}$$

Comparing Equation (9) with Equation (2) shows that the differential equation may be written in terms of the average velocity and average concentration, provided an effective diffusivity is used:

$$E = D + KV_o d \tag{10}$$

In most practical cases D is small compared with $KV_o d$. Therefore,

$$E = KV_o d \tag{11}$$

These arguments show that the effect of the packing needs to be considered only insofar as it affects the effective diffusivity. The latter is defined either by Equations (10) and (11), or by the Einstein equation relating the diffusivity to the mean square deviation of a diffusing particle in a given time. Thus, the effective diffusivity due to the presence of the packing may be obtained by evaluating the mean square deviation of a particle resulting from the random deflections of the fluid in the bed. For simplicity, consider a two-dimensional bed, and picture the motion of a particle suspended in the fluid. Whenever the particle approaches a pellet, it suffers a lateral deflection $\pm\beta d$, where β is of the order of one half. The sign of the deflection is controlled by chance. Suppose, now, that the particle has progressed a distance, Z, in the direction of flow. Then it undergoes $n = \alpha Z/d$ deflections, where α is approximately unity. The total lateral deflection is

$$Y = \pm\beta d \pm \beta d \pm \beta d \pm \ldots \pm \beta d \tag{12}$$

where there are altogether n terms in the sum. Clearly $Y_{av} = 0$. The mean square deviation is

$$\overline{\Delta Y^2} = n\beta^2 d^2 = \alpha Z\beta^2 d \tag{13}$$

This follows immediately from Equation (12), since the product of any two terms in this equation is positive or negative with equal likelihood. The sum of such products, therefore, vanishes in the averaging process. From the Einstein equation

$$\overline{\Delta Y^2} = 2E\theta \tag{14}$$

where θ is the time corresponding to $\overline{\Delta Y^2}$. In the present case

$$\theta = \frac{Z}{V_o} \tag{15}$$

Eliminating $\overline{\Delta Y^2}$, θ, and Z from Equations (13), (14) and (15)

$$E = \frac{\alpha\beta^2}{2} dV_o = \frac{\alpha\beta^2}{2}\left(\frac{dV_o\rho}{\mu}\right)\left(\frac{\mu}{\rho}\right) \tag{16}$$

or

$$\left(\frac{\mu}{\rho E}\right)\left(\frac{dV_o\rho}{\mu}\right) = Sc'Re' = Pe' = \frac{2}{\alpha\beta^2} \tag{17}$$

Similar conclusions were reached independently by Ranz (*11*) who calculated effective diffusivities by estimating the lateral fluctuations for various packing arrangements. A slightly different statistical derivation is given by Singer (*16*) and Baron (*1*). Comparing Equations (11), (16) and (17)

$$K = \frac{\alpha\beta^2}{2} = \frac{1}{Pe'} \tag{18}$$

While α is approximately unity, the value of β should range between 0.4 and 0.7. The predicted range of the Pe' number is therefore between 5 and 13. Due to the sensitiveness of the Pe' number with respect to small variations in β, the above analysis yields only semiquantitative results. It is important to note that the derivations are limited to small values of d/D_T, say to $d/D_T < 0.1$, since for larger values of this group the statistical concepts used would not be expected to hold.

Figure 1 shows the effective diffusivities of hydrochloric acid in water flowing by gravity through a 9-in. inside diameter tower packed with ½-in. Berl saddles (*6*). The acid was introduced at the top center of the bed. The effective diffusivities were determined from

---

* In deriving Equation (5) diffusion in the direction of the mean flow is neglected. Note also that

$$\overline{D\ \text{grad}\ C_i} = D\ \text{grad}\ \overline{C_i}$$

$$+ \overline{D\ \text{grad}\ c_i} = D\ \text{grad}\ \overline{C_i}$$

since the average of the gradient of the concentration fluctuation vanishes.

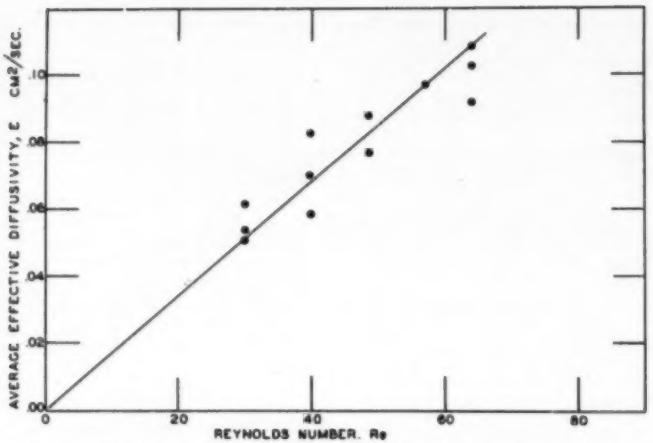


Fig. 1. Effective diffusivity of acid through water. Tower diameter 9 in.; packing 0.5 in. Berl saddles.

measured concentration profiles using the method described by Sherwood (*14*). Within experimental error, the effective diffusivity is seen to be proportional to the Reynolds number, as expected from Equation (16). The Pe' number calculated from the slope of the straight line is 6, and is thus in the expected range.

Bernard and Wilhelm (*2*) report Pe' groups for carbon dioxide diffusing in air, and dye diffusing in water. Their results also indicate proportionality between effective diffusivity and Reynolds number. Values of the Pe' group, and the corresponding effective diffusivity differed only by about 15% between water and gas systems. Singer and Wilhelm (*15*) compare these Pe' numbers with Pe' numbers obtained for heat transfer, which on the basis of the random walk argument should be identified with the Pe' numbers for mass transfer. This comparison is shown in Figure 2, together with the Pe' numbers obtained from the effective diffusivities shown in Figure 1. Considering experimental uncertainties, the data for heat and mass transfer are in excellent agreement, the Pe' numbers ranging from 5 to 15.

In the general case of simultaneous heat and mass transfer with chemical reaction, V_o and $\overline{C_t}$ are functions of the temperature. Assuming that the superficial mass velocity, G_o, is constant, or at any rate that its variations may be neglected, and recognizing that

$$\overline{C_t} = \frac{\rho y_t}{M_{av}} \tag{19}$$

one obtains from Equations (8), (18), and (19)

$$\frac{dG_o}{Pe' M_{av}} div\ grad_t\ y_t - \frac{1}{M_{av}} div\ \vec{G}_o y_t - \overline{R}_t \rho_B = 0 \tag{20}$$

Subjecting Equation (1) to similar treatment one obtains

$$\frac{C_p dG_o}{Pe'} div\ grad_t\ t - C_p\ div\ (\vec{G}_o t) + \overline{R}_t \rho_B \lambda = 0 \tag{21}$$

The effective thermal conductivity is then

$$k_e = \frac{C_p dG_o}{Pe'} \tag{22}$$

where the Pe' group is again defined by Equations (16) and (17).

For the purpose of obtaining graphical solutions of Equations (20) and (21) the following transformations and modifications are convenient. The vector $\vec{G}_o$ has only one nonvanishing component, namely, the superficial mass velocity G_o in the direction of flow (Z axis), and, because of continuity, $div\ \vec{G}_o = 0$, thus, Equations (20) and (21) become after rearrangement

$$\frac{\partial y_t}{\partial Z} = \frac{d}{Pe'} div\ grad_t\ y_t - \frac{\overline{R}_t \rho_B M_{av}}{G_o} \tag{23}$$

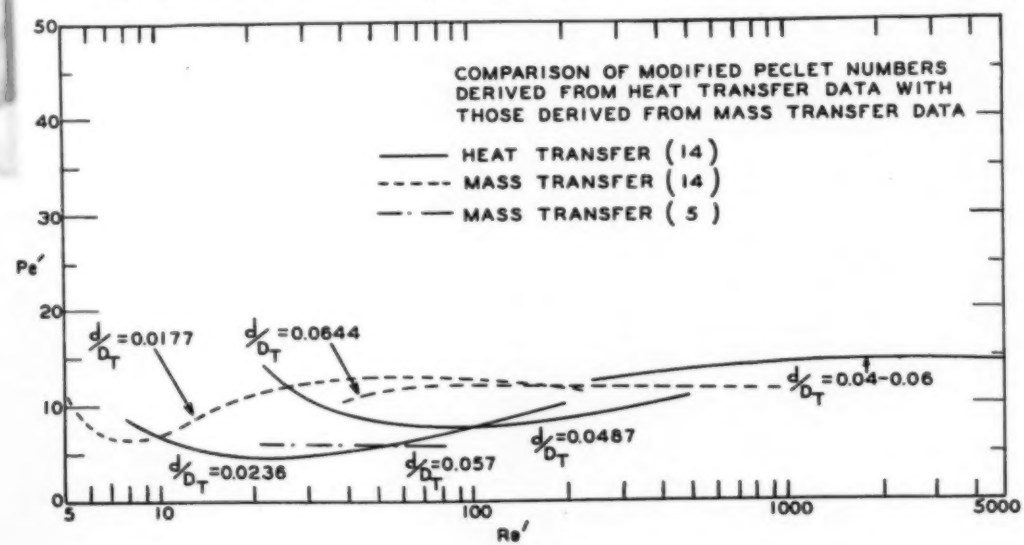


Fig. 2.

and

$$\frac{\partial t}{\partial Z} = \frac{d}{Pe'} \, div \; grad_t \, t + \frac{\overline{R_1}\rho_B\lambda}{C_pG_o} \tag{24}$$

Consider now a set of dimensionless co-ordinates, obtained by dividing the dimensional co-ordinates by the pellet diameter d(e.g.: $Z' = Z/d$). Then

$$\frac{\partial y_i}{\partial Z'} = \frac{1}{Pe'} \, div \; grad_i \, y_i - \frac{R_i\rho_B M_{av} d}{G_n} \; ; n = 1, 2, \ldots n \tag{25}$$

and

$$\frac{\partial t}{\partial Z} = \frac{1}{Pe'} \, div \; grad_i \, t + \frac{\overline{R_i}\rho_B\lambda d}{C_pG_o} \tag{26}$$

In order to obtain a solution, Equations (25) and (26) have to be solved simultaneously. Simultaneous solution is necessary because the reaction rates $\overline{R_i}$ depend in general on all the mole fractions y_i as well as on the temperature, t. Fortunately a considerable simplification may now be introduced. In many practical applications the total number of moles passing through the reactor is either constant or varies only insignificantly. The latter is true, for example, when the inerts are present in large amounts, or, when the conversion is low. Under these conditions it can be shown from Equations (25) (see Appendix) that in spite of lateral diffusion, the reactants are always present in stoichiometric amounts, i.e., the mole ratios are precisely those that one would obtain from stoichiometric calculations for a batch reaction. Hence, among Equations (25) only the equation for the limiting reactant needs to be considered. Equation (26) and Equation (25) written for the limiting reactant may now be put into their respective finite difference forms and solved simultaneously by either graphical or numerical methods. An additional simplification can be made using the fractional conversion f, of the limiting reactant, rather than its mole fraction. Then

$$y_1 = y_1^\circ(1 - f) \tag{27}$$

Eliminating y_1 from Equations (25) and (27)

$$\frac{\partial f}{\partial Z'} = \frac{1}{Pe'} \, div \; grad_i \, f + \frac{R_1\rho_B M_{av} d}{y_1^\circ G_o} \tag{28}$$

where f is the fractional conversion of the limiting reactant. Equations (26) and (28) should be expressed in terms of the coordinate system appropriate to the symmetry of the reactor. For cylindrical symmetry

$$\frac{\partial t}{\partial Z'} = \frac{1}{Pe'}\left[\frac{\partial^2 t}{\partial r'^2} + \frac{1}{r'}\frac{\partial t}{\partial r'}\right] + \frac{R_1\rho_B\lambda d}{C_pG_o} \tag{29}$$

and

$$\frac{\partial f}{\partial Z'} = \frac{1}{Pe'}\left[\frac{\partial^2 f}{\partial r'^2} + \frac{1}{r'}\frac{\partial f}{\partial r'}\right] + \frac{R_1\rho_B M_{av} d}{G_o y_1^\circ} \tag{30}$$

Graphical Solutions. Following Nessi and Nisolle (*9*), Equations (*29*) and (30) may be transformed by means of the substitution

$$\xi = \log_{1.2} r' \tag{31}$$

One obtains

$$\frac{\partial t}{\partial Z'} = \frac{1}{Pe'(2.3r')^2}\frac{\partial^2 t}{\partial \xi^2} + \frac{R_1\rho_B\lambda d}{C_pG_o} \tag{32}$$

and

$$\frac{\partial f}{\partial Z'} = \frac{1}{Pe'(2.3r')^2}\frac{\partial^2 f}{\partial \xi^2} + \frac{R_1\rho_B M_{av} d}{G_o y_1^\circ} \tag{33}$$

or in the form of difference equations

$$\frac{\Delta Z' t}{\Delta Z'} = \frac{1}{Pe'(2.3r')^2}\frac{\Delta^2\xi t}{(\Delta\xi)^2} + \frac{R_1\rho_B\lambda d}{C_pG_o} \tag{34}$$

and

$$\frac{\Delta Z' f}{\Delta Z'} = \frac{1}{Pe'(2.3r')^2}\frac{\Delta^2\xi f}{(\Delta\xi)^2} + \frac{R_1\rho_B M_{av} d}{y_1^\circ G_o} \tag{35}$$

Finally, since

$$\Delta\xi = \frac{\Delta r'}{2.3r'} \tag{36}$$

the desired design equations are

$$\Delta_2 t = \frac{1}{Pe'}\frac{\Delta Z'}{(\Delta r')^2}\Delta^2\xi t + \frac{R_1\rho_B\lambda d}{C_pG_o}\Delta Z' \tag{37}$$

and

$$\Delta_2 f = \frac{1}{Pe'}\frac{\Delta Z'}{(\Delta r')^2}\Delta^2\xi f + \frac{R_1\rho_B M_{av} d}{G_o y_1^\circ}\Delta Z' \tag{38}$$

with

$$R_1 = R_1(f, t) \tag{39}$$

Equations (37) and (38) may be solved graphically using a modification of the method developed by Binder (*3*), Schmidt (*12, 13*) and Nessi and Nisolle (*9*). See also (*8, 14*). First an interval $\Delta r'$ is chosen ($\Delta r' = 1$ is frequently convenient). Then $\Delta Z'$ is obtained from

$$\frac{1}{Pe'}\frac{\Delta Z'}{(\Delta r')^2} = \frac{1}{2} \tag{40}$$

A chart of the type illustrated in Figure 3 is then prepared. Using experimental data given in or converted to the form of Equation (39) the auxiliary lines of quadrants II and III are prepared. In quadrant II, the quantity $R'\rho_B\lambda d\Delta Z'/C_pG_o$ is plotted as a function of temperature using the fractional conversion as a parameter. Similarly in quadrant III, the quantity $R_1\rho_B M_{av} d\Delta Z'/G_o y_1^\circ$ is plotted as a function of the fractional conversion, using the temperature as a parameter. The ξ axis common to quadrants I and IV is then divided into intervals corresponding to $\Delta r'$.

Assume, now, that the distribution of temperature and fractional conversion is known at a bed depth $Z' = n\Delta Z'$. The corresponding points with subscript n are indicated in the figure. Then the new temperature at any radial position (corresponding to $Z' = (n+1)\Delta Z'$), say at $r' = (m-3)\Delta r'$, may be obtained by the following procedure:

1. Connect points n,m-4 and n,m-2 in the quadrants I and IV, thus locating points A and D.
2. From point n,m-3 draw horizontal lines in both quadrants, locating points C and F. Point C corresponds to the fractional conversion read at E, whereas point F corresponds to the temperature read at B.
3. Add the distance $\overline{CB}$ to point A (bracketed distance) in the first quadrant, thus obtaining the desired temperature at $Z' = (n+1)\Delta Z'$. Similarly in the third quadrant, the new fractional conversion may be located by adding the distance $\overline{FE}$ to point D.

In starting it is sometimes convenient to use some of the special procedures developed in connection with the Schmidt method (*10*). When the superficial mass velocity varies over the radius it is recommended that the plots in the second and third quadrant be based on the average mass velocity. Then the distances $\overline{CB}$ and $\overline{FE}$ should be multiplied by G_{av}/G_r', before addition to points A and D. Clearly, near the wall, the mass velocity is smaller than the average mass velocity, resulting in decreased effective thermal conductivities. In the absence of experimental information concerning the radial distribution of the mass velocity the assumption of rod-like flow is recommended with this exception: The mass velocity in the interval next to the wall should be taken as half of the average mass velocity.

Frequently the wall temperatures are unknown. In these cases the wall temperatures may be established from the temperature and film coefficient of the heat transfer medium by a method analogous to that used in connection with the Schmidt method. In particular, on any line through which no heat is transferred (e.g., a line representing a well insulated wall, center line or any other line of symmetry), the diffusional part of the temperature change is obtained by drawing a horizontal line through the old point on the neighboring line. Changes in fractional conversion on such lines are handled similarly.

This method is applicable for any initial temperature distribution and for all heat-exchange situations in which some simple symmetry may be assumed. Consider, for example, a catalyst bed pierced with cooling tubes, the centers of which are at the apexes of equilateral triangles, as shown in Figure 4. Clearly the points B, C, D, E, F, and G are points of symmetry, such that at these points $\partial t/\partial r' = \partial f/\partial r' = 0$, where r' is measured from point A. As a first approximation it is permissible to consider that these derivatives vanish over the circle $BCDEFB$. Then for purposes of design it is sufficient to consider a cylindrical reactor pierced at the center by a single cooling tube, the insulated wall of which coincides with this circle.

Illustrative Example. Hall and Smith (*7*) report differential and integral re-

actor data for the oxidation of sulfur dioxide on a platinum catalyst. From the differential reactor data they predict the performance of the integral reactor using Grossman's method (5), and compare the calculated temperatures and conversions with measured values. Results for the temperature distribution are in fair agreement with the experimental temperatures. However, the calculated conversion of the limiting reactant is only 15% as compared with the experimental value of 30%.

Data of Hall and Smith may be used to test the present method. The pertinent design information is given below.

Diam. of chamber =	$D_T = 2$ in.
Depth of bed =	8 in.
Wt. of catalyst =	435.5 g.
Wall temp. =	100° C.
Catalyst size =	$d = \frac{1}{8}$ in.
Mass velocity =	$G_o = 350$ lb./(hr.) (sq.ft.)
Initial mole fraction of SO_2 =	$y_1^\circ = 0.064$
Heat of reaction =	$\lambda = 23{,}000$ cal./g.mole
Effective thermal conductivity =	$k_e = 0.2$ B.t.u./(hr.) (ft.) (° F.)

Then

$$C_p \cong 0.936 \times 0.248 + 0.064 \times 0.172$$

$$= 0.243 \text{ cal./(g.mole) (° C.)}$$

$$M_{av} \cong 0.936 \times 29 + 0.064 \times 64 = 31.3$$

$$\rho_B = \frac{435.5}{8 \times 2.54 \times \pi \times (2.54)^2} = 1.06 \text{ g./cc.}$$

$$Pe' = \frac{dG_oC_p}{k_e} = \frac{\frac{1}{8} \times 350 \times 0.243}{12 \times 0.2} = 4.4$$

Let $\Delta r' = 1$, then from Equation (40)

$$\Delta Z' = \frac{Pe'}{2} = \frac{4.4}{2} = 2.2$$

$$\frac{R_1\rho_B\lambda d\Delta Z'}{C_pG_o} = \frac{1.06 \times 23{,}000 \times 0.125 \times 2.54 \times 2.2 \times 930}{0.243 \times 350 \times 453.6} = 410\,R_1 (^\circ \text{C.})$$

$$\frac{R_1\rho_B M_{av} d\Delta Z'}{y_1^\circ G_o} = \frac{1.06 \times 31.3 \times 0.125 \times 2.54 \times 2.2 \times 930}{0.069 \times 350 \times 433.6} = 2.22\,R_1$$

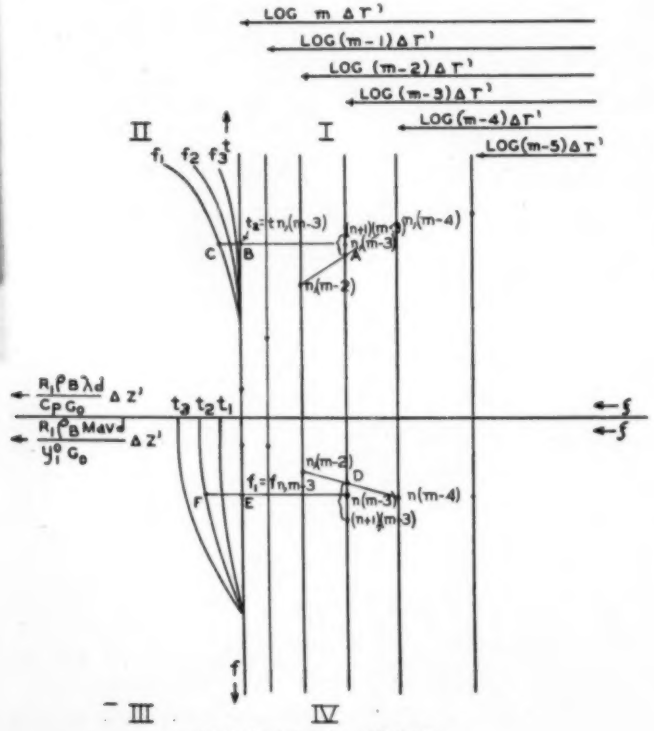


Fig. 3. Illustration of graphical design.

The auxiliary curves in quadrants II and III may now be constructed using values of R_1, read from Figure 6 (7). The initial temperature distribution is read from Figure 10. The graphical procedure outlined above is then started. In order to prevent the various components from "leaking" through the wall, the conversions at the wall ($r' = 8$) are always set equal to the conversion at $r' = 7$. This procedure effectively prevents diffusion across the wall because it insures that the concentration gradients at the wall vanish for all values of Z'.

Results of the graphical design are shown in Figure 5. The temperature profiles for various values of the fractional radius n are seen to be in good agreement with experiment, although the improvement on the calculated results of Hall and Smith (not shown in Figure 5) is only slight. The calculated average over-all conversion of the limiting reactants is 25% as compared with the experimental value of 30%, and 15% as calculated by the above investigators. This indicates the improvement resulting from taking into account the lateral diffusion of mass. Thus, the present method appears to be a significant advance from Grossman's method. Presumably, the agreement between the calculated and experimental results could be improved further if the radial distribution of the mass velocity were known.

Notation

- C = concentration
- c = concentration fluctuation
- C_p = specific heat at constant pressure
- D = diffusivity
- D_T = diameter of reactor
- d = diameter of catalyst pellet
- E = effective diffusivity
- f = fractional conversion of limiting reactant
- G = mass velocity
- K = constant
- k = thermal conductivity of fluid
- k_e = effective thermal conductivity of bed
- M = molecular weight
- R = rate of conversion per unit mass of catalyst
- r = radial coordinate
- t = temperature of fluid
- V = velocity
- v = velocity fluctuation
- Z = longitudinal coordinate
- y = mole fraction
- α = constant, characteristic of the packing
- β = constant, characteristic of the packing
- λ = heat of reaction
- ρ = density of the fluid
- ρ_B = mass of catalyst per unit volume of bed
- θ = time
- μ = viscosity of fluid

Subscripts

- o indicates superficial quantities
- av = average
- i refers to ith component
- j refers to jth component
- l refers to lateral coordinate

Superscripts

- — indicates averaging
- → refers to vector quantities
- ° refers to conditions at entrance of reactor

Appendix

Consider the reaction

$$aA + bB + \ldots = sS + \ldots \qquad (A\text{-}1)$$

and visualize a batch process starting with known mole fractions of A, B, S, . . . , and inerts. At any fractional conversion f, of the limiting reactant A, the mole fraction y_j, of any component may be related to the initial mole fractions of all components, and to y_1, the mole fraction of A:

$$y_j = y_j^\circ + K(y_1 - y_1^\circ) \qquad (A\text{-}2)$$

Furthermore, if the total number of moles is approximately constant

$$R_j = \frac{dy_j}{dy_1} R_1 = KR_1 \qquad (A\text{-}3)$$

where K is a stoichiometric constant, e.g., $R_B = bR_A/a$ and $R_S = -SR_A/a$

Equation $(A\text{-}3)$ holds under all conditions, therefore, at any point in a fixed bed reactor. It is shown here that Equation $(A\text{-}2)$ also holds at any point in a fixed bed reactor, provided the assumptions leading to Equations (25) are permissible.

Consider Equations (25) written with subscripts j and 1, and eliminate R_j using Equation $(A\text{-}3)$. Then

$$\frac{\partial y_1}{\partial Z'} = \frac{1}{Pe'} \, div \; grad_l \, y_1 - \frac{\rho_B M_{av} d}{G_o} R_1 \qquad (A\text{-}4)$$

and

$$\frac{\partial y_j}{\partial Z'} = \frac{1}{Pe'} \, div \; grad_l \, y_j - \frac{\rho_B M_{av} d}{G_o} KR_1 \qquad (A\text{-}5)$$

Multiplying Equation $(A\text{-}4)$ by K and subtracting the resulting Equation from $(A\text{-}5)$

$$\frac{\partial (y_j - Ky_1)}{\partial Z'} = \frac{1}{Pe'} \, div \; grad_l \, (y_j - Ky_1) \qquad (A\text{-}6)$$

with the boundary condition

$$y_j - Ky_1 = y_j^\circ - Ky_1^\circ = \text{const at } Z' = 0 \qquad (A\text{-}7)$$

The unique solution of Equation $(A\text{-}6)$ for condition $(A\text{-}7)$ is (3)

$$y_j - Ky_1 = y_j^\circ - Ky^\circ \qquad (A\text{-}8)$$

or

$$y_j = y_j^\circ + K(y_1 - y_1^\circ) \qquad (A\text{-}9)$$

which is identical with Equation $(A\text{-}2)$. Thus, in spite of lateral diffusion, the mole fractions of all components are related to each other by the stoichiometric relation.

Literature Cited

1. Baron, T., Ph.D. Thesis, University of Illinois (1948).
2. Bernard, A. R., and Wilhelm, R. H., *Chem. Eng. Progress*, **46**, 233 (1950).
3. Binder, L., Dissertation, Munich (1911).
4. Courant, R., and Hilbert, D., "Methoden Der Mathematischen Physik," Vol. 2, pp. 156-159, Julius Springer, Berlin (1937).
5. Grossman, L. M., *Trans. Am. Inst. Chem. Engrs.*, **42**, 535 (1946).
6. Hacker, D., Effect of Flow Conditions on Mass and Heat Transfer in Packed Beds, B.S. Thesis, University of Illinois (1949).
7. Hall, R. E., and Smith, J. M., *Chem. Eng. Progress*, **45**, 459 (1949).
8. Jakob, M., "Heat Transfer," John Wiley & Sons, New York (1949).

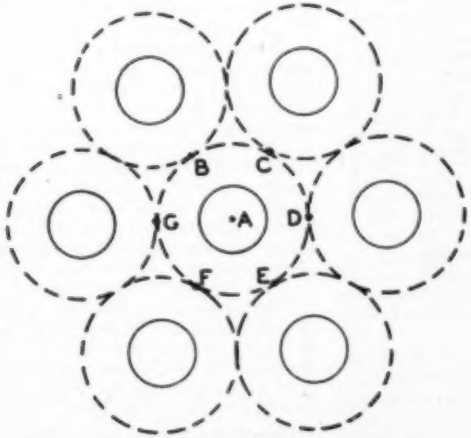


Fig. 4. Representative cross section of bed pierced by tubes.

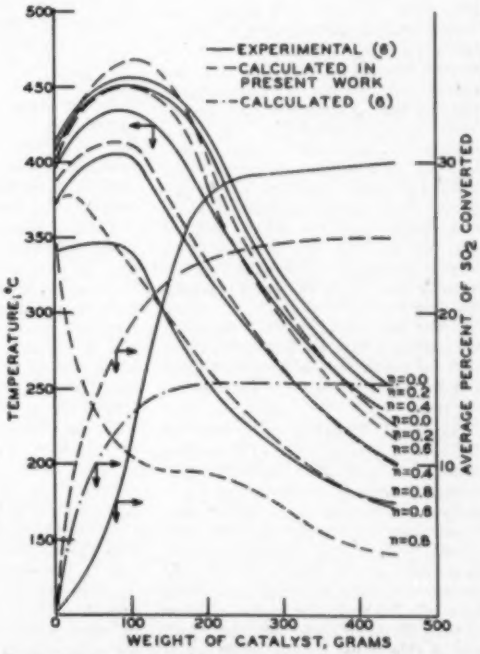


Fig. 5. Comparison of experimental and calculated temperatures and conversions.

9. Nessi, A., and Nisolle, L., "Methodes Graphiques pour L'Etude des Installations de Chauffage et de Refrigeration en Regime Discontinu," Dunad, Paris (1929).
10. Perry, R. L., and Berggren, W. P., *Univ. Calif. (Berkeley) Pubs. Eng.*, **5**, 59 (1944).
11. Ranz, W. E., Oral Communication (May, 1950).
12. Schmidt, E., Föppl-Festschrift, 179-198 (1924).
13. Schmidt, E., *Forsch. Gebiete Ingenieurw.*, **13**, No. 5, 177 (1942).
14. Sherwood, T. K., and Reed, C. E., "Applied Mathematics in Chemical Engineering," McGraw-Hill Book Co., New York (1939).
15. Singer, E., and Wilhelm, R. H., *Chem. Eng. Progress*, **46**, No. 7, 343 (1950).
16. Singer, E., Ph.D. Thesis, Princeton University (1949).
17. Yang, K. H., and Hougen, O. A., *Chem. Eng. Progress*, **46**, 146 (1950).

Discussion

R. E. Wilhelm (Princeton (N. J.) University): Would you care to make a comment about getting started at the beginning of a bed in the computational procedure?

Thomas Baron: There are various ways of getting started at the beginning of the bed. These may depend as much on taste as on convenience and on the particular problem at hand. In principle, no special starting procedure is necessary and one may start with the general procedure. This will work whenever the temperatures at the beginning of the bed are sufficiently low and consequently the conversions in the first few steps are not too high. In the opposite case, special starting procedures may become necessary. One possibility is to use a modulus of 3 or 4 rather than a modulus of 2 in the Schmidt method. Another possibility which should be useful frequently is to use an analytical solution at the beginning of the reactor. In doing this, one must be careful to check the solution to make sure that the approximations involved in the analytical solution are valid. In general, we should consider the special methods developed in connection with the Schmidt method, both for use at the beginning of the bed and for use near the walls and the center-line.

Raymond Wynkoop (Standard Oil Co. (Ind.), Whitney, Ind.): In looking at the experimental vs. calculated temperature curves of Smith's data, I was rather disappointed that your fraction conversions didn't quite match as well as one might desire. In looking at it, particularly on the rate of rise of your temperature profiles, might you have been injudicious in the choice of some of your thermodynamic data and might you be able to get a little better correspondence if your data were refined. I note your fraction conversion rise curve and Smith's rise curve have quite a sort of a hysteretic loop between them, and one might be willing to guess, if Smith's observations had been correct, that the front end of his curve followed pretty close to adiabatic operation and that yours should, too. If it didn't, perhaps your choice of the thermodynamic data had not been too good.

Thomas Baron: I think your point is well made. The effect of temperature on the physical and thermodynamic properties might become quite important, and I feel sure that taking into account these changes, the correspondence between the calculated curves and the experimental curves of Smith's could be improved. However, the effect of these changes would probably be less than the uncertainties inherent in (a) some of the assumptions involved in the theory, (b) the wall effect and, (c) the particular starting procedure used.

Actually, we have approximately 15 solutions to this problem obtained by parcelling out the problem to members of our senior class. Some of these solutions come considerably closer to the experimental data than the one I reported which represents my first attempt. I purposely refrained from reporting the best solution since I feel that this might give an unfair idea of the accuracy of the method proposed. In this connection, I might mention that C. H. Barkelew of Shell Development Co. has also solved this problem assuming a constant average temperature at the beginning of the bed. His solution agrees almost exactly with Smith's final conversion.

W. R. Manning (Carbide & Carbon Chemicals, S. Charleston, W. Va.): Dr. Baron, have you given any thought to applying this method to cases where there are competing reactions? That makes the problem more complicated.

Thomas Baron: Yes, I have. Sometimes in the case of competing reactions, one can make assumptions which result in considerable simplifications. In the general case, however, competing reactions will complicate severely the problem by introducing new differential equations. In this case, the differential equation for each component has to be carried along in the solution together with the differential equation for the heat balance. I believe that in most practical cases, our knowledge of the rate of the various competing reactions does not justify the considerable amount of work that would be involved in such a solution.

C. C. Watson (University of Wisconsin, Madison, Wis.): There is one question that I've never seen worked out and that is whether or not in some of the small reactors that we use in experimental work we don't have a serious by-passing effect along the walls. One indication that there may be such a problem is shown by the wall effect corrections in the packed bed pressure drop correlation of Colburn. All too frequently, however, due to lack of time, we make kinetics experiments on only one bed size and then we have absolutely no way of knowing how serious this effect is. Probably we ought to consider in most of our experiments, running at least two different tubes sizes if not more, just as a check to see if there isn't some effect like this. It might be a serious error in scaling-up and we might be seriously misled if we don't consider it. Another possibility, experimentally of course, is to use various means of roughening the inside of the wall of the tube.

Thomas Baron: Professor Watson has pointed to an important problem. I agree that it is highly desirable to conduct experiments with several tube sizes. We all know, however, the large amount of labor involved in obtaining a complete set of data for a single tube. I, therefore, feel that this problem will stay with us for a long time.

There is one particular wall effect which can be taken into account by some rather rough reasoning. In the method presented, the mean square deviation and therefore the effective diffusivity of any particle is a function of the number of obstacles met on its way. The assumption was made that at every obstacle the deflection is random. Suppose now that at certain particles there is a Maxwell's demon which nullifies the deflection occurring at the obstacle by insuring that the deflection is immediately followed by deflection of the opposite sign. The effect of these demons is simply to cancel the effect of the obstacles at which they are stationed. We would therefore calculate our diffusion coefficient by disregarding the obstacles equipped with demons. We might think of the wall as being such a demon with respect to obstacles right next to the wall. For instance, if a particle is deflected by such an obstacle toward the wall, the next deflection must of necessity occur away from the wall (this, of course, is true only for a two-dimensional bed). We may, therefore, get an effective diffusivity by multiplying the effective diffusivity obtained disregarding the wall effect by one minus the ratio of the number of particles next to the wall and the total number of particles. Strictly speaking, this procedure would be justified only if the particles with the demons were distributed at random. However, the results obtained are in good agreement with the results reported by Singer and Wilhelm.

(Presented at Minneapolis (Minn.) Meeting.)

REACTION KINETICS IN A TUBULAR REACTOR

THOMAS BARON,† W. R. MANNING,‡ and H. F. JOHNSTONE

University of Illinois, Urbana, Illinois

In a porous tubular reactor impregnated with vanadium oxide catalyst diffusional resistance to the oxidation of sulfur dioxide is less than ten per cent of the total resistance to the reaction. There is a pronounced effect of the nature of the inert gas on the rate and activation energy, which may be explained by the momentum exchange between the gas and adsorbed molecules. A generalization of Bodenstein's theory accounts satisfactorily for earlier results on the kinetics of the reaction as well as those of the present work.

MOST catalytic reaction rate studies in flow systems have been performed in packed beds. Although practical applications of the results are often successful, complications arising from thermal gradients, short-circuiting of the catalyst, diffusion, and irregular flow patterns make fundamental analysis of the reaction kinetics extremely difficult. Of the few technics developed for semiempirical analysis, the most successful are the differential reactor of Hougen and Watson (*5*) and, in a restricted sense, the reaction unit concept of Hurt (*6*). In the differential reactor, a shallow bed of catalyst is used so that the conditions along the axis of the bed are essentially constant. Hurt's concept, which is analogous to the transfer unit in gas absorption, expresses the effectiveness of the catalyst in terms of the thickness of the bed necessary to obtain a change in the concentration of the limiting reactant equal to the mean driving potential of the reaction. This concept is applicable only to first-order, or pseudo first-order reactions.

The tubular reactor, in which a cylindrical tube carrying the catalyst deposited on the wall is used, is more suitable for obtaining precise kinetic measurements interpretable in terms of the basic factors which affect reaction mechanisms: the flow pattern is simple; samples may be obtained readily at any point in the reactor; accurate temperature control of the catalyst surface is possible; surface concentration of the catalyst is controllable; and all parts of the catalyst surface are equally accessible to the reactants.

In the present work, data were obtained in two tubular reactors on the oxidation of sulfur dioxide catalyzed by vanadium oxide (*1, 7*). Results show a surprising effect of the nature of the inert gas on the rate and activation energy of this reaction. This phenomenon led to a theoretical investigation of the nature of the interaction between the phases during the course of a heterogeneous reaction and demonstrated the general applicability of the method to precise studies of reaction mechanisms in flow systems. Later studies using the tubular reactor have been made on the catalytic hydrogenation of ethylene, the reaction of carbon monoxide and hydrogen, and on the reaction of steam with carbon. These will be reported in later papers.

Theory of the Tubular Reactor. Damköhler has presented a simplified mathematical analysis of first-order reactions in a tubular reactor (*3*). This will be outlined briefly and extended to reversible reactions. Consider a tubular reactor in which the fluid moves by rodlike, frictionless and nonturbulent flow and in which a constant volume, heterogeneous reaction occurs. For steady state, a material balance over a differential volume element in the reactor yields the equation

$$D\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C}{\partial r}\right)+\frac{\partial^2 C}{\partial x^2}\right] - v\frac{\partial C}{\partial x}=0 \qquad (1)$$

The boundary condition for a first-order surface reaction is

$$-D\left(\frac{\partial C}{\partial r}\right)_{r=\frac{d}{2}} = kC_{r=\frac{d}{2}} \qquad (2)$$

The solution of Equation (1) for this condition is

$$\frac{C_e}{C_a}=\sum_{n=1}^{\infty}\frac{4}{\eta_n^2\left[1+\eta_n^2\left(\frac{2D}{kd}\right)^2\right]}e^{-\eta_n^2\tau} \qquad (3)$$

where the η_n are the roots of

$$\eta_n\frac{J_1(\eta_n)}{J_0(\eta_n)}=\frac{kd}{2D} \qquad (4)$$

Equation (3) has the form

$$\frac{C_e}{C_a}=Ae^{-a\tau}+Be^{-b\tau}+Ce^{-c\tau}+\ldots \qquad (5)$$

where

$$\tau=\frac{4DL}{v d^2}$$

The constants in Equation (5) are shown in Table 1 for various values of the group $kd/2D$. A graphical representation of Equation (5) is shown in Figure 1. For a reversible reaction of the first order in both directions, a similar analysis yields

$$\frac{C_e-C^*}{C_a-C^*}=\sum_{n=1}^{\infty}\frac{4}{\eta_n^2\left[1+\eta_n^2\left(\frac{2D}{kd}\right)\right]}e^{-\eta_n^2\tau} \qquad (6)$$

where now

$$k=\left(\frac{K+1}{K}\right)k_f \qquad (7)$$

The approach to equilibrium as given by Equation (6) is illustrated graphically in Figure 2.

The analysis of data from first-order reactions is based on Equations (3) and (6). Data are plotted as shown in Figures 1 and 2, and from a comparison of the resulting curves with theoretical curves for various values of $kd/2D$ the value of this group is determined. The group $kd/2D$ represents the ratio of the mean time required for diffusion to the mean reaction time. The specific reaction rate constant, k, is obtained directly from the group if the diffusivity of the limiting reactant is known. The activation energy is determined from the specific reaction rate constants at different temperatures in the usual manner.

Experimental. The apparatus used is shown in Figure 3. It consisted essentially of a catalyst tube assembly with preheater and exhaust tube, flow meters for oxygen and inert gas, a sulfur dioxide pump, gas-sampling equipment, a voltage regulator, and transformers for controlling the heat input to the catalyst assembly, a potentiometer and a six-point temperature recorder. The catalyst support tubes were obtained from the Norton Co., Worcester, Mass., and were made of refractory alun-

† Present address: Shell Development Co., Emeryville, Calif.

‡ Present address: Carbide and Carbon Chemicals Co., Union Carbide and Carbon Corp., South Charleston, W. Va.

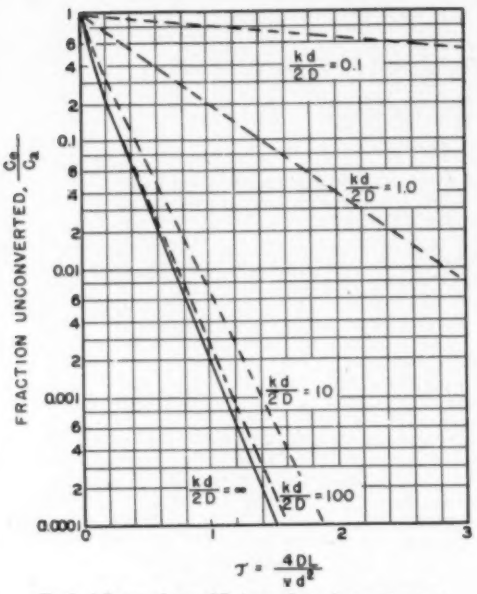


Fig. 1. Influence of cross diffusion on first-order reactions in a cylindrical tube. (3)

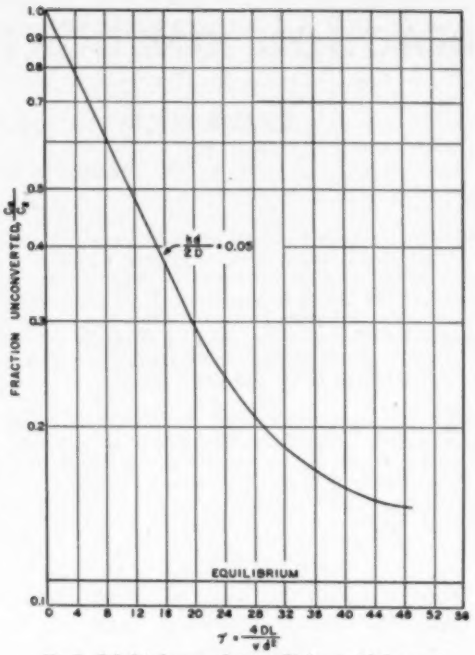


Fig. 2. Calculated approach to equilibrium in tubular reactor.

lium RA 98. The porosity was stated to be 47%, and the thermal conductivity 6 to 7 B.t.u./(hr.)(sq.ft.)(° F./ft.). Two sizes of tubes were used, ½ in. and ¼ in. I.D. Both were 24 in. long and ⅛-in. wall thickness. Alundum as the catalyst support was chosen because of its inertness, its high thermal conductivity and uniform porosity. The tubes were impregnated with the catalyst by immersing them in dilute potassium metavanadate solution. After soaking for short intervals in the solution, they were dried, weighed, and replaced in the solution. This procedure was repeated until they showed no further gain in weight. The catalyst deposited in this manner on the ½-in. tube amounted to 6.47% of the total weight of the tube, and on the ¼-in. tube to 7.25% of the total weight.

To provide a large thermal capacity in order to facilitate temperature control in the reactor, the catalyst tube was surrounded by a heavy cylindrical brass billet as shown in Figure 4. The reaction tube was sealed in the billet with a thin layer of alundum cement. The temperature difference between the billet and porous tube, as measured by thermocouples, never exceeded 0.5° C. Thus it was possible to rely on thermocouples placed in wells drilled to near the inside surface of the billet for measurements of the temperature of the reactor. Experience showed that four heating elements, one wound over the entire length and the others each wound over one third of the billet, permitted accurate temperature control of the reactor.

The flow rates of oxygen and of the inert gas were measured by calibrated capillary flow meters. The flow rate of sulfur dioxide was controlled and measured by displacement with mercury which was in turn displaced by oil with a Zenith metering pump.

The concentration of sulfur dioxide in the exit gas stream was determined by standard analytical methods. A Whatman extraction thimble was used as a filter to collect the sulfuric acid mist. Results of the analysis and the flow measurements provided a complete material balance around the reactor.

The experimental conditions were chosen to fit the assumptions made in the derivation of Equations (3) and (6) as closely as possible. Steady state was insured before sampling. Pressure changes in the tube were negligible compared to the static pressure. The reactor was isothermal, and, even at maximum conversion, the molar gas rate was essentially constant. For absorption and vaporization in short wetted wall columns with streamline flow, Sherwood (9) found that the flow was rodlike rather than parabolic. These considerations justify the assumption of rodlike flow for the experiments performed in this work. For small conversions the graphs of the logarithm of the per cent sulfur dioxide unconverted aganist τ are straight lines as indicated by Equation (3), showing that the assumption of first-order reaction is correct.

The diffusivities of sulfur dioxide in the mixtures were calculated from the equation of Gilliland (4) using molal averages of molar volumes of the inert constituents. These values agree within 5% for helium

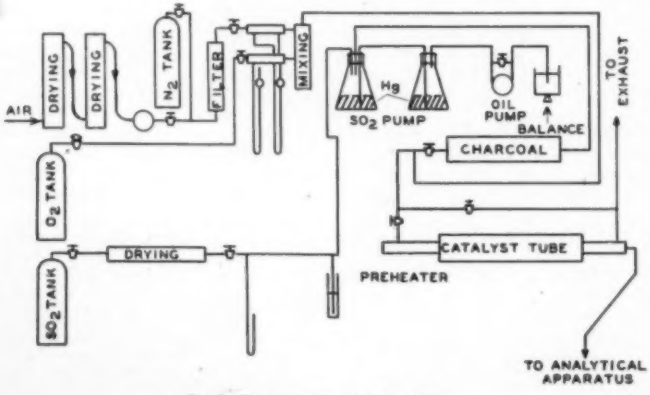


Fig. 3. Flow system for catalytic studies.

and 12% for carbon dioxide with those estimated from a chart given by Sherwood (*8*) showing the variation in diffusivity with molecular weight for a number of systems. The value used in each case was the lower of those obtained from the two methods of estimation. These are shown in Table 2. The probable error in the diffusivities thus obtained is estimated as 8%.

Results obtained with the ¼-in. and ½-in. catalyst tubes are shown in Tables 3 to 5 and in Figures 5 to 10. Values shown under "Fraction Unconverted" are averages of several analyses taken at constant gas velocity after steady-state performance had been obtained. In general, these analyses agreed within ±5%. The reproducibility of the data are shown in Figures 6 to 10. Data shown for each gas velocity were not all taken consecutively but usually represent checks made after changing the velocity and temperature of the catalyst through a cycle. Continued operation of the catalyst sometimes resulted in a sudden change (usually lowering) of its activity. This was not always explainable but may have been due to poisoning by oil or mercury vapor. A prolonged period of activity was obtained with the ¼-in. tube after a charcoal trap was placed in the individual gas lines. With the ½-in. tube, the catalyst was first activated at 500° in the presence of air and sulfur dioxide. After steady performance was obtained the temperature and composition of the gas could be changed without altering the activity of the catalyst. When the runs were not being made, the tube was maintained at about 425° C. without any gas flow. Steady-state and reproducible performance was quickly attained after the temperature was adjusted and the gas flow was started, as indicated by analysis of successive samples of the exit gas.

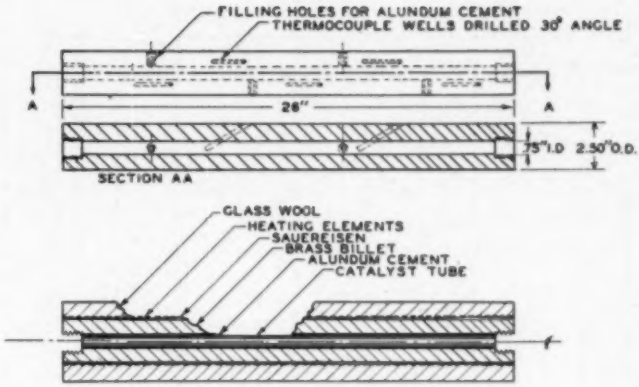


Fig. 4. Construction details of catalytic tube.

TABLE 1.—CONSTANTS IN EQUATION (5) FOR TUBULAR REACTOR

$\frac{kd}{2D}$	A	a	B	b	U	c
100	0.718	5.57	0.1338	29.91	0.0542	73.3
10	0.804	4.75	0.1257	25.40	0.0388	63.2
1	0.962	1.600	0.0136	16.65	1.49×10^{-3}	51.3
0.1	0.929	0.2025	1.82×10^{-4}	14.82	1.64×10^{-5}	49.4

TABLE 2.—DIFFUSIVITIES OF SULFUR DIOXIDE USED IN CALCULATIONS

Inert Gas	Diffusivities, sq.cm./sec.					
	425°	450°	475°	500°	525°	550° C.
Nitrogen	0.42	0.45	0.47	0.49	0.51	0.54
Helium	....	0.87	....	0.95	....	1.04
Carbon dioxide	....	0.34	....	0.38	....	0.42

Performance of Catalyst During Initial Unsteady State. The initial unsteady-state performance of the catalyst in the ¼-in. reactor immediately after the first introduction of the sulfur dioxide is shown in Figure 5. Of the first 0.16 moles of sulfur dioxide passed into the reactor, no sulfur compounds were recovered. This indicated one of three possibilities, (a) the gas was adsorbed and remained on the catalyst; (b) it was converted to the trioxide which remained on the catalyst; or (c) a part was converted to the trioxide, with the catalyst holding both types of molecules. To decide between these possibilities, sulfur dioxide was passed through the catalyst in the presence of nitrogen alone. In this case, 98% of the dioxide passed into the reactor was recovered, indicating that little, if any, of the dioxide was held as such on the catalyst. Hence the catalyst was covered primarily with sulfur trioxide molecules.

Figure 5 also shows that the first appearance of sulfur gases was followed by a rapid increase in the per cent sulfur recovered. A recovery of 100% was reached at

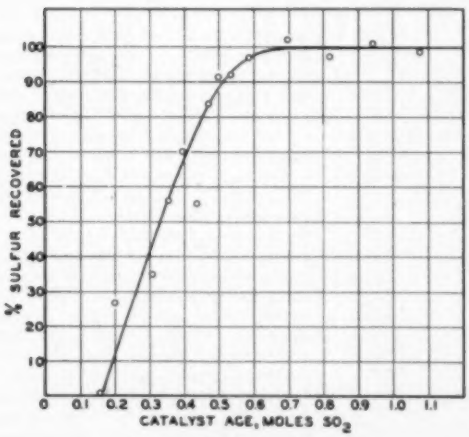


Fig. 5. Material balance in reactor.

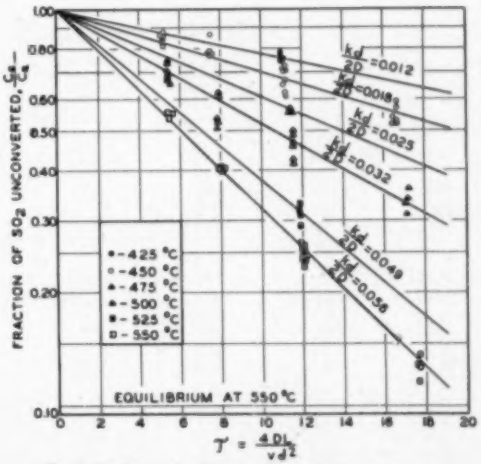


Fig. 6. Oxidation of sulfur dioxide in presence of nitrogen. 0.5-in. reactor.

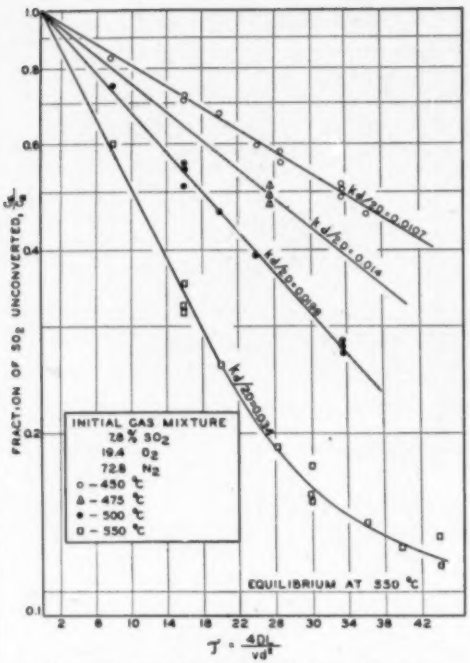


Fig. 7. Oxidation of sulfur dioxide with air. 0.25-in. reactor.

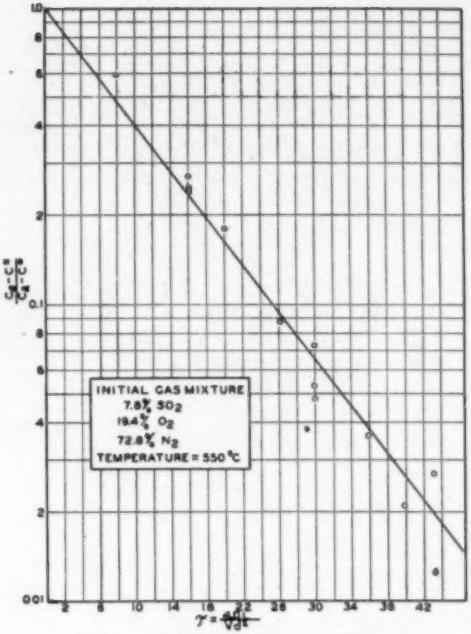


Fig. 8. First-order reversible reaction. 0.25-in. reactor.

a catalyst life corresponding to about 0.65 moles of sulfur dioxide through the reactor. The average recovery during the period of rapid saturation was approximately 50%. The amount of sulfur dioxide held on the catalyst surface at the activation temperature of 450° C. was therefore $0.16 + 0.5(0.65 - 0.16) = 0.56$ moles. This figure may be compared with the amount of catalyst in the tube. Assuming one active center for each vanadium atom, the 11 g. of potassium metavanadate deposited correspond to 0.0796 moles of active centers. Thus, at most, only 14% of the sites holding the trioxide molecules was provided by the catalyst.

Steady-State Results. Figures 6, 9 and 10 show the results obtained after the steady state was reached in the ½-in. reactor, while Figures 7 and 8 show results from the ¼-in. reactor. For small conversions, the plots are straight lines as required by Equation (3), while for large conversions they approach the equilibrium line asymptotically. The 450° C. curve in Figure 7 is replotted in Figure 8 as suggested by Equation (6). The resulting straight line indicates that this equation accounts properly for the reverse reaction. Results show that the group $kd/2D$ increases with temperature. This is expected, of course, in view of the fact that an increase in temperature, while having only a small effect on the diffusion rate, significantly increases the reaction rate. In all cases the group $kd/2D$ is less than 0.10, indicating that for the experimental conditions the diffusional resistance is but a small part of the total resistance.

The specific reaction rate constants calculated from the group $kd/2D$ are shown as functions of temperature in Table 6 and Figure 11. Comparing the data for nitrogen obtained in the two reactors, it appears that the specific reaction rate constants for the ¼-in. reactor were approximately 12% higher than the corresponding rate constants for the ½-in. reactor. This may be compared with the approximately 20% higher catalyst content per unit weight in the ¼-in. reactor.

The most significant result of the work is the pronounced effect of the nature of the inert gas on the reaction rate and the activation energy. Table 7

TABLE 3.—OXIDATION OF SULFUR DIOXIDE IN PRESENCE OF NITROGEN
INITIAL GAS COMPOSITION: 7.8% SO_2, 19.4% O_2, 72.8% N_2

Gas Velocity v cm./sec.	$\frac{4DL}{vd^2}$	Fraction Unconverted C_e/C_o
	¼-in. reactor	
	$t = 450°$ C.	
8.1	33.4	0.50
7.5	36.0	0.46
10.1	26.7	0.57
11.2	24.1	0.60
13.5	20.0	0.67
16.8	16.1	0.72
24.6	7.8	0.84
	$t = 475°$ C.	
11.1	25.4	0.49
	$t = 500°$ C.	
9.0	32.3	0.28
12.3	24.2	0.40
14.9	20.0	0.46
18.6	16.0	0.54
37.3	8.0	0.75
	$t = 550°$ C.	
7.4	44.1	0.12
8.3	39.6	0.13
9.0	36.2	0.14
10.8	30.0	0.16
12.4	26.3	0.19
16.3	20.0	0.27
20.3	16.1	0.33
4.0	16.5	0.58
6.1	11.1	0.70
9.0	7.5	0.78
13.0	5.2	0.85
	$t = 475°$ C.	
6.2	11.5	0.56
	$t = 500°$ C.	
4.3	17.2	0.35
6.4	11.6	0.45
9.4	7.9	0.53
13.9	5.4	0.68
	$t = 525°$ C.	
6.6	11.9	0.31
	$t = 550°$ C.	
4.6	17.7	0.13
6.7	12.1	0.24
10.0	8.1	0.40
14.9	5.5	0.55

shows the activation energies for the reaction in the presence of the various inert gases, calculated from the best straight lines through the data in Figure 11. One might assume at first that the inert gases are adsorbed to various degrees, thus interfering more or less with the reaction. This assumption, however, is hardly tenable. In the first place, at the high temperatures involved, only negligible adsorption of the inert gas can take place, certainly not sufficient to produce the pronounced effects observed. Furthermore, it hardly seems possible that helium, the most inert of the gases used, should be adsorbed to the highest degree, thus interfering with the reaction to the greatest extent. Finally, while adsorption of the inert gas may decrease the reaction rate by decreasing the number of available reaction sites, this should have no effect on the activation energy. A fundamental consideration of momentum and energy exchanges between the phases of heterogeneous reactions explains the observed effects, and throws considerable light on the mechanism. The effect of the molecular weight of the inert gas on the rate and activation energy of a desorption reaction appears as a direct consequence of this interaction.

Influence of Molecular Collisions on Desorption Reaction. Consider a catalyst surface holding molecules of species A in a chemisorbed state on certain active points. The surface is in contact with a gas consisting of molecules of species B. Assume that (a) molecules A have no vibrational or rotational motions, (b) the rate of reaction is small compared with the rate at which thermal equilibrium is established, (c) steady-state conditions prevail, and (d) the desorption reaction takes place as a result of collisions between molecules A and B.

By a straightforward application of the kinetic theory of gases, the total number of collisions per unit time per unit surface between molecules A and molecules B having a velocity V is

$$dr_c = 4\pi^2 \nu_0 P \left(\frac{m_B}{2\pi kT}\right)^{3/2} e^{-\frac{m_B}{2kT}V^2} S_{AB} V^3 dV \qquad (8)$$

Here P is a steric factor which allows for the possibility that a certain amount of space between the molecules A and the surface might not be accessible to molecules of type B. The possibility of removal of A molecules is not taken into account in Equation (8), since, by the assumption of steady state, an A molecule, if removed, is immediately replaced by another.

From the point of view of reaction kinetics, however, not all collisions involved in Equation (8) are "successful," i.e., only some collisions result in the activation of a molecule of species A. After collision, a molecule A must possess kinetic energy equal to or in excess of the energy of activation in order to escape. It now remains to determine the fraction of all collisions given by Equation (8) which are successful in the above sense.

A typical collision is illustrated in Figure 12. According to the theory of elastic collisions, the component of the relative velocity lying in the tangent plane of the collision remains unaltered by the impact. The normal component, $V \cos \gamma$, however, while unaltered in magnitude, changes its sign, and thus becomes $-V \cos \gamma$. The law of conservation of momentum demands that the sum of the momenta along the line of centers remain unaltered by collision. Thus, since the molecule A is initially at rest,

$$m_B V \cos\gamma = m_A V_A + m_B V_B \qquad (9)$$

But

$$V_B - V_A = -V \cos \gamma \qquad (10)$$

Also, if the collision is to be successful

$$\frac{1}{2} m_A V_A^2 \geq \frac{E_d}{N} \qquad (11)$$

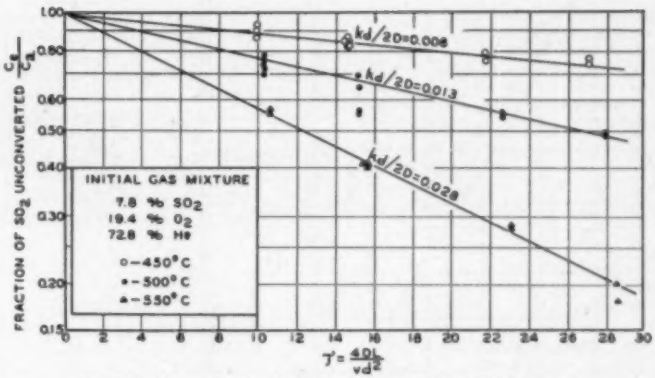


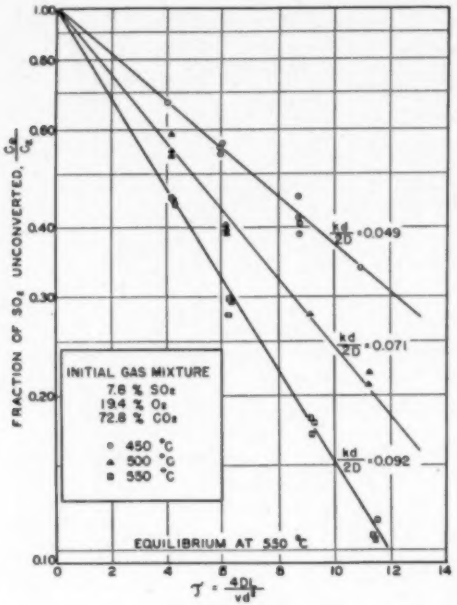
Fig. 9. Oxidation of sulfur dioxide in presence of helium. 0.5-in. reactor.

TABLE 4.—OXIDATION OF SULFUR DIOXIDE IN PRESENCE OF CARBON DIOXIDE
INITIAL GAS COMPOSITION: 7.8% SO_2, 19.4% O_2, 72.8% CO_2
½-in. tubular reactor

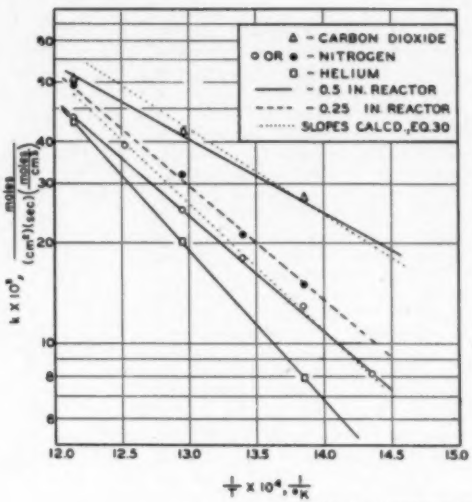
Gas Velocity v cm./sec.	$\frac{4DL}{vd^2}$	Fraction Unconverted C_a/C_o	Gas Velocity v cm./sec.	$\frac{4DL}{vd^2}$	Fraction Unconverted C_a/C_o
	$t = 425°$ C.			$t = 500°$ C.	
5.8	8.5	0.41	5.2	11.2	0.22
	$t = 450°$ C.		6.4	9.1	0.38
			9.5	6.1	0.40
4.8	10.9	0.24	14.9	4.1	0.56
6.0	8.7	0.43		$t = 525°$ C.	
8.9	5.9	0.50	6.6	9.3	0.19
12.0	4.0	0.67		$t = 550°$ C.	
	$t = 475°$ C.		5.5	11.5	0.11
6.2	8.9	0.31	6.8	9.2	0.16
			10.3	6.3	0.30
			14.9	4.3	0.45

TABLE 5.—OXIDATION OF SULFUR DIOXIDE IN PRESENCE OF HELIUM
INITIAL GAS COMPOSITION: 7.8% SO_2, 19.4% O_2, 72.8% HC
½-in. reactor

Gas Velocity v cm./sec.	$\frac{4DL}{vd^2}$	Fraction Unconverted C_a/C_o	Gas Velocity v cm./sec.	$\frac{4DL}{vd^2}$	Fraction Unconverted C_a/C_o
	$t = 450°$ C.		6.4	22.7	0.54
			9.4	15.3	0.66
4.8	27.3	0.74	13.9	10.4	0.73
6.0	21.8	0.77		$t = 525°$ C.	
8.8	14.7	0.83	6.6	23.8	0.24
12.0	10.0	0.88		$t = 550°$ C.	
	$t = 475°$ C.		5.5	28.7	0.19
6.2	22.2	0.66	6.8	23.2	0.28
	$t = 500°$ C.		10.0	15.7	0.41
5.1	28.0	0.48	14.9	10.7	0.56



◀ Fig. 10. Oxidation of sulfur dioxide in presence of carbon dioxide. 0.5-in. reactor.


Δ - CARBON DIOXIDE
○ OR ● - NITROGEN
□ - HELIUM
- 0.5 IN. REACTOR
- 0.25 IN. REACTOR
SLOPES CALCD. EQ. 30
k x 10³, moles/(cm²)(sec)(moles/cm³)
1/T x 10⁴, 1/°K

▲ Fig. 11. Reaction rates for oxidation of sulfur dioxide.

Combining Equations (9), (10), and (11)

$$V \cos \gamma \geqq \frac{m_A + m_B}{2m_B} \sqrt{\frac{2E_d}{m_A N}} \tag{12}$$

Since the maximum value of cos γ is 1,

$$V_{min} = \frac{m_A + m_B}{2m_B} \sqrt{\frac{2E_d}{m_A N}} \tag{13}$$

From Equations (12) and (13)

$$\cos \gamma \geqq \frac{V_{min}}{V} \tag{14}$$

Hence, the larger the ratio of the initial relative velocity to the minimum velocity for successful collision, the less critical are the requirements concerning the direction at the moment of impact.

Since the probability that the angle between the direction of the relative velocity and the line of centers has a value between γ and $\gamma + d\gamma$ is proportional to sin γ, the probability of successful collision is

$$\frac{\int_o^{\gamma_{max}} \sin \gamma \, d\gamma}{\int_o^{\pi/2} \sin \gamma \, d\gamma} = 1 - \frac{V_{min}}{V} \tag{15}$$

Multiplying Equation (8) by this probability, the total number of "successful" collisions per unit time per unit surface area is obtained for a relative velocity whose magnitude is in the range V to $V + dV$. Integration between the limits V_{min} and infinity, and the substitutions

$$\alpha = \frac{m_A}{m_B} \text{ and } \nu = \frac{pN}{RT} \tag{16}$$

yield the total number of successful collisions per unit time and unit area of catalyst surface, which, in turn, can be recognized as the rate of desorption due to molecular collisions:

$$r = 2NpPS^2_{AB} \sqrt{\frac{2\pi}{m_B RT}} \left[e^{-\frac{(1+\alpha)^2}{4\alpha} \frac{E_d}{RT}} - \sqrt{\frac{\pi(1+\alpha)^2 E_d}{16\alpha RT}} \, erfc \sqrt{\frac{(1+\alpha)^2 E_d}{4\alpha RT}} \right] \theta \tag{17}$$

The rate of desorption is given thus by the difference of two terms, one containing an exponential function, and the other an error function. The first term represents the rate of successful collisions, provided that all collisions are center to center. The second term corrects for the "poor marksmanship" of the molecules.

For practical application it is convenient to simplify Equation (17). Consider the following expansion:

$$1 - erfcx = \frac{2}{\sqrt{\pi}} \int_o^x e^{-x^2} dx$$

$$= 1 - \frac{e^{-x^2}}{\sqrt{\pi}} \left(\frac{1}{x} - \frac{1}{2x^3} + \frac{3}{4x^5} - \cdots \right) \tag{18}$$

Retaining the first term only

$$erfcx \cong \frac{1}{x} \frac{e^{-x^2}}{\sqrt{\pi}} \tag{19}$$

Equation (19) is in error by not more than 6%, provided $x > 3$. With the aid of Equation (19), Equation (17) may be rearranged to give a good approximation of the desorption rate due to molecular collisions:

$$r_D = S^2_{AB} \theta N p P \sqrt{\frac{2\pi}{m_B RT}} \, e^{-\frac{(1+\alpha)^2}{4\alpha} \frac{E_d}{RT}} \tag{20}$$

Defining the apparent energy of activation by the Arrhenius equation

$$r_D = Ze^{-\frac{E_A}{RT}} \theta \tag{21}$$

Equation (22) is obtained by comparison with Equation (20)

$$E_A = \frac{(1+\alpha)^2}{4\alpha} E_d \tag{22}$$

Thus the apparent activation energy for desorption is a function of the ratio of the average molecular weight of the product and the molecular weight of the gas to be desorbed. Only when this ratio is unity is the observed apparent activation energy equal to the true energy of activation.

Equation (22) is restricted of course to desorption reactions in which most of the desorption results from molecular

collisions. Even if only a small part of the desorption reaction is due to such collisions, however, there still should be some effect of the molecular weight of the gases on the apparent energy of activation. Also, the above treatment may be extended to any reaction taking place on a catalyst surface. It is possible therefore that the apparent activation energies of many catalytic reactions are affected to some degree by the average molecular weight of the gases above the catalytic surface.

Apparent Activation Energy for Catalytic Oxidation of Sulfur Dioxide. The early study of the mechanisms of oxidation of sulfur dioxide by Bodenstein is classical. In recent years, several authors have offered alternative mechanisms based on data from carefully controlled experiments using modern catalysts (*1, 6, 8, 10*). The method of determining reaction mechanisms by fitting experimental data to equations derived for various postulations has serious limitations. The investigation of all possible mechanisms entails a prohibitive amount of work. The investigator is therefore limited to consideration of only a few comparatively simple mechanisms which he considers plausible. At present, the science of reaction kinetics is not sufficiently advanced to serve as a reliable guide in the choice of possible mechanisms. As a result, the equations proposed are, at best, semiempirical. They are useful, however, for design purposes, provided the design does not necessitate extrapolation of the equations to conditions not investigated in the experiments.

For these reasons, no attempt is made in the present work to determine a definite reaction mechanism. Rather, the object is to show that it is possible on the basis of a simple mechanism to describe analytically the effect of inert gases on the activation energy. The mechanisms proposed previously yield equations containing one or more empirical constants. Essentially, the equations differ only in the retarding effect of the sulfur trioxide concentration. The arguments presented below are based on the mechanism suggested by Bodenstein which, while no less plausible than the others, results in a one-constant equation. Similar arguments undoubtedly could be prescribed on the basis of more complicated mechanisms.

Bodenstein (*2*) found that the rate of oxidation of sulfur dioxide on a platinum catalyst can be expressed by

$$r = k\frac{C_{SO_2}}{\sqrt{C_{SO_3}}} \qquad (23)$$

and that the nature of the inert gas has little if any effect on the reaction rate. The present work shows that the reaction rate on a vanadium oxide catalyst, while first order in the concentration of sulfur dioxide, is not affected by the concentration of sulfur trioxide, but is considerably influenced by the nature of the inert gas.

These apparently contradictory results can be explained. Equation (*23*) was derived on the basis of the assumption that the controlling step in the reaction is the diffusion of sulfur dioxide on the catalyst surface toward certain active points where instantaneous reactions occur. The reaction rate is then proportional to the gradient of the concentration of the sulfur dioxide, and is inversely proportional to the resistance offered to the diffusion by absorbed sulfur trioxide molecules, which, in turn, is proportional to the square root of the sulfur trioxide concentration. If surface diffusion is truly the controlling step in the reaction, however, the concentrations affecting the rate of reaction should be those on the surface, rather than the bulk concentrations. Accordingly, Equation (*23*) should be modified to read

$$r = k\frac{\theta_{SO_2}}{\sqrt{\theta_{SO_3}}} \qquad (24)$$

At steady state the surface concentration of any of the absorbed molecules must remain constant. Therefore the following equation must hold for the surface concentration of sulfur trioxide:

$$k_a C_{SO_3}(\theta_O - \theta_{SO_3}) + k\frac{\theta_{SO_2}}{\sqrt{\theta_{SO_3}}} = k_d\theta_{SO_3} \qquad (25)$$

The three terms in Equation (*25*) represent the adsorption rate, reaction rate, and desorption rate of sulfur trioxide, respectively. Since the results of the present work indicate that the reaction rate is independent of the bulk concentration of sulfur trioxide, it is apparent that, for the experimental conditions used here, the first term of Equation (*25*) is negligible in comparison to the second. With this assumption, and indicating the exponential dependence of the diffusion rate on temperature, Equation (*25*) becomes

$$k'e^{-\frac{E_D}{RT}}\frac{\theta_{SO_2}}{\sqrt{\theta_{SO_3}}} = k_d\theta_{SO_3} \qquad (26)$$

Contracting the constants in Equation (*20*) into one and substituting the resulting expression for the desorption rate of sulfur trioxide into Equation (*26*)

$$k'e^{-\frac{E_d}{RT}}\frac{\theta_{SO_2}}{\sqrt{\theta_{SO_3}}} = \frac{k'_d}{M}e^{-\frac{(1+a)^2}{4a}\frac{E_d}{RT}} \qquad (27)$$

Before proceeding further, it is necessary to obtain a relationship between the activation energy for diffusion, E_D, and the activation energy for desorption, E_d. Since the major obstacle to the diffusion of sulfur dioxide is presented by the absorbed molecules of sulfur trioxide, it is reasonable to interpret the activation energy for diffusion as the energy a sulfur dioxide molecule must possess to displace a sulfur trioxide molecule in its way. Therefore, assume

$$E_d = \frac{E_D}{l} \qquad (28)$$

where l is some positive number. Putting Equation (*28*) into Equation (*27*), solving for θ_{SO_2}, and substituting the resulting expression into either side of Equation (*27*)

$$r = \frac{k''}{M_{av}^{1/6}}e^{-\left[\frac{2}{3l}+\frac{(1+a)^2}{12a}\right]\frac{E_D}{RT}}\theta_{SO_2}^{2/3} \qquad (29)$$

Comparing this equation with the Arrhenius equation, the apparent activation energy of the reaction is obtained as a function of the activation energy of desorption of sulfur trioxide and the

TABLE 6.—REACTION RATE CONSTANTS

Temperature, °C.	$\frac{kd}{2D}$ ½-in. reactor	$\frac{kd}{2D}$ ¼-in. reactor	$k \times 10^5$, $\frac{\text{moles}}{(\text{sq. cm.})(\text{sec.})\left(\frac{\text{moles}}{\text{cc.}}\right)}$ ½-in. reactor	$k \times 10^5$ ¼-in. reactor
		A. Inert gas: Nitrogen		
425	0.012	.....	8.1	..
450	0.018	0.011	13	15
475	0.025	0.014	18	21
500	0.032	0.020	25	32
525	0.049	.....	39	..
550	0.056	0.034	47	59
		B. Inert gas: Helium		
450	0.006	.....	7.9	..
500	0.013	.....	20	..
550	0.029	.....	46	..
		C. Inert gas: Carbon dioxide		
450	0.049	.....	27	..
500	0.071	.....	43	..
550	0.092	.....	61	..

TABLE 7.—ACTIVATION ENERGIES IN THE PRESENCE OF VARIOUS INERT GASES

Inert Gas	Activation Energy cal./mole
Helium	21,000
Nitrogen	15,800
Carbon dioxide	9,500

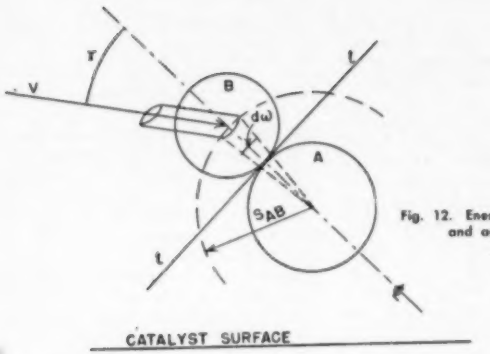


Fig. 12. Energy transfer between gas and adsorbed molecules.

mass ratio, a,

$$E_A = \left(\frac{2}{3t} + \frac{(1+a)^2}{12a}\right) E_D \quad (30)$$

The agreement between this equation and the experimental results is shown by the dotted lines in Figure 11. For these, the apparent activation energy calculated from the slope of the straight line for the data with helium was used to calculate (assuming $t = 1$) the apparent activation energies and slopes corresponding to the nitrogen and carbon dioxide runs. The dotted line calculated for nitrogen fits the data within the experimental accuracy. The line calculated for the carbon dioxide runs is equally good if the high temperature point, which is least reliable, is disregarded.

Bodenstein's results may be explained by assuming that, under the conditions of his experiments, the reaction rate was slow compared to the rate of desorption of sulfur dioxide and rate of adsorption of sulfur trioxide, as might be expected with a less active catalyst. Under these conditions the surface concentrations of these gases are in equilibrium with their bulk concentrations, and for low values of the latter, they are proportional to them. Thus Equation (23) follows immediately from Equation (24).

The agreement of this theory with experimental data may of course be fortuitous. It is not possible to prove the validity of Bodenstein's concept of the mechanism of the catalytic oxidation of sulfur dioxide. There seems to be little doubt, however, that whatever the actual mechanism of the catalytic oxidation, the effect of inert gases on the activation energy of this reaction is due to the type of momentum exchange just discussed.

Acknowledgment

The authors wish to express their appreciation to the Standard Oil Company (Indiana) for the support of a fellowship which made this investigation possible.

Notation

C = concentration of limiting reactant, moles/cc.; subscripts a and e refer to average concentrations at entrance and exit of reactor; superscript * refers to equilibrium value corresponding to reactor temperature

d = inside diameter of tubular reactor, cm.

D = diffusivity of limiting reactant, sq.cm./sec.

e = base of natural logarithm

E = activation energy; subscripts D and d refer to diffusion and desorption, respectively; subscript A indicates apparent activation energy

$$G_a = \frac{-v}{2D} + \sqrt{\left(\frac{v}{2D}\right)^2 + \left(\frac{2\eta_n}{d}\right)^2} \approx \frac{4\eta_n^2 D}{vd^2}$$

J_0 = Bessel function of zero order and first kind

J_1 = Bessel function of first order and first kind

k = specific reaction rate constant; subscripts a and d refer to adsorption and desorption, respectively; subscript f refers to forward reaction; moles converted/(sq.cm.)(sec.)(moles/cc.)

k = Boltzmann's constant

K = equilibrium constant

L = length of reactor

m = molecular mass

M = molecular weight; subscript avg. refers to average for gases in reactor

n = running index

N = Avogadro's number

p = pressure, dynes/sq.cm.

P = steric factor

r = cylindrical coordinate, cm.

r = rate j subscripts c and D refer to collision and desorption, respectively

R = gas constant

S = distance between centers of colliding molecules

t = a positive number

T = absolute temperature, ° K.

v = average velocity of gases in reactor, cm./sec.

V_A = velocity of molecule A after collision along the line of centers, cm./sec.

V_B = velocity of molecule B after collision along the line of centers, cm./sec.

V = relative velocity before collision, cm./sec.; subscript *min* refers to minimum value of V necessary to insure desorption

Z = frequency factor

x = cylindrical coordinate, cm.

$$erfc\,x = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-x^2} dx$$

$$a = \frac{m_A}{m_B}$$

γ = angle formed by line of centers and direction of relative velocity before collision; subscript *max* refers to maximum allowable value for given value of V if desorption is to occur

θ = surface concentration; subscript o refers to total number of active centers per unit area

ν = molecular density, mole/cc.

$\tau = 4DL/vd^2$

Literature Cited

1. Baron, T., "The Effect of Flow Conditions on Catalytic Yields," Ph.D. Thesis, University of Illinois, Urbana, Ill. (1948).
2. Bodenstein, M., *Z. Physik. Chem.*, **B2**, 345 (1939).
3. Damköhler, G., *Z. Elektrochem.*, **42**, 846 (1936).
4. Gilliland, E. R., *Ind. Eng. Chem.*, **26**, 681 (1934).
5. Hougen, O. A., and Watson, K. M., "Chemical Process Principles," Part III, John Wiley & Sons, New York (1947).
6. Hurt, D., *Ind. Eng. Chem.*, **35**, 522 (1943).
7. Manning, W. R., "The Effect of Diffusion and Fluid Properties on the Yield in Contact Catalysis," Ph.D. Thesis, University of Illinois, Urbana, Ill. (1944).
8. Olson, R. W., Schuler, R. W., and Smith, J. M., *Chem. Eng. Progress*, **46**, No. 12, 614 (1950).
9. Sherwood, T. K., "Absorption and Extraction," McGraw-Hill Book Co., New York (1937).
10. Uyehara, O., and Watson, K. M., *Ind. Eng. Chem.*, **35**, 541 (1943).

(*Presented at Minneapolis (Minn.) Meeting.*)

THE EFFECT OF ORIENTATION AND SHAPE

ON THE SETTLING VELOCITY OF NON-ISOMETRIC PARTICLES IN A VISCOUS MEDIUM

JOHN F. HEISS † and JAMES COULL

University of Pittsburgh, Pittsburgh, Pennsylvania

WHERE a fluid flows in laminar motion through a porous bed, estimation of the pressure drop and fluidization characteristics are desirable. If the bed is packed with particles of a constant size and shape, the effect of the random orientation of these particles might be found by knowing the resistance of a single particle of the same dimensions in various degrees of orientation.

In view of the many applications to classification and sedimentation, a study of the settling rates of various shapes of particles was considered valuable. From these data it was expected that a general correlation could be developed from which orientation and shape effects could be predicted for freely falling particles. A need for research of this type has been stressed by Pettyjohn and Christiansen (*19*) in their paper dealing with freely settling isometric particles.

Previous Work

For the past century Stokes' law (*24*) for a sphere falling freely in a viscous fluid has been well accepted. Perry (*18*) lists many investigators whose combined experimental data verify Stokes' law.

Oberbeck (*16*) developed an integral equation for the ellipsoid from which its resistance to motion in a viscous fluid is made equal to that of a sphere. Since Oberbeck's general equation for the resistance of an ellipsoid is difficult to integrate when all the semi-axes are of different values, Gans (*7*) simplified the resistance equation by assuming an ellipsoid of revolution (spheroid). He proved analytically that a body possessing three perpendicular symmetry planes has no tendency to assume any particular orientation as it settles in a viscous fluid. The resistance equations for very thin disks, settling edgewise and broadside in a viscous fluid, have been derived from the general, analytical equation for the ellipsoid, developed by Oberbeck. The case of viscous motion transverse to a long, elliptic cylinder has been treated analytically by Bairstow (*1*), using the "linearized" equation of Oseen (*14*) as a basis in the investigation. The flow across thin disks and infinitely long cylinders was considered to be two-dimensional only for all of these derivations.

The first experimental study of the effect of orientation on the settling rate of non-isometric particles was made by Squires and Squires (*23*). Using blended mineral oils, they settled very thin, aluminum disks, ranging in thickness-to-diameter ratio of 0.00062 to 0.0063, edgewise and broadside. Their correlation related the drag coefficient to the Reynolds' number by a single curve for both positions of orientation. Similar studies to those of Squires and Squires were made recently by Kunkel (*12*). In his investigations thin aluminum disks, squares, and rectangles were settled broadside in a viscous fluid. The projected area of the flat shapes was varied as the volume remained constant. Schmiedel (*21*) dropped thin disks moving with their flat faces in the direction of motion. Wieselsberger (*28*) conducted experiments in the turbulent region with thin disks of various diameters and cylinders with a length-diameter ratio of five.

The effect of Reynolds' number and boundary distance on cylinders falling sideways in fluids at slow speeds has been recently studied by White (*27*). He found that at slow speeds the resistance was independent of the density of the fluid when the fluid is limited by the boundary distances.

Other regular, geometric shapes, such as prisms and cubes, received attention from early investigators, such as Schultz (*22*) and Pernolet (*17*), who collected experimental data over limited Reynolds' number ranges. Heywood (*9*) experimented in the range of Reynolds' numbers from 0.01 to 1,000 with five different shapes, defined only by their volume shape factor values.

Much interest has been shown of late for the effect of shape on the free-settling rates of particles. Krumbein (*11*) has conducted studies within the turbulent region with several geometric shapes. The contribution of Pettyjohn and Christiansen on the free-settling rates of isometric particles in all three regions of flow is an important contribution. Malaika (*15*) has completed the most recent work on the effect of shape on the settling velocity of nonisometric particles. He settled 12 different geometric shapes of particles within the viscous and transition regions where most of the problems of free fall occur. The particles in all cases were oriented and settled in their most stable positions only.

From a careful survey of the previous work mentioned, it was observed that only Squires and Squires treated orientation experimentally as a specific variable. All other investigators oriented and settled the particles in their most stable positions. A lack of experimental data appeared to exist for nonisometric particles settling within the streamline region. It was concluded, therefore, that for the streamline region experimental settling data should be obtained on cylinders and rectangular parallelepipeds with orientation as the important variable to be studied. Similar data would be obtained for spheroids from the analytical work by Gans. These data would prove to be useful in evaluating orientation and shape effects for these three families of particles with the possibility of a general correlation being developed which would enable one to determine the settling rate of any shape of particle in a viscous medium.

Theoretical Considerations

For a sphere of diameter, d_s, moving with a constant velocity, u_s, in streamline motion through a fluid infinite in extent whose viscosity is μ, the resistance, R, to the sphere can be expressed as follows:

$$R = 3\pi d_s u_s \mu \qquad (1)$$

The pure number, 3π, can be found experimentally but was originally determined analytically by Stokes who used a stream current function. It is interesting to note that, in general, the resistance encountered by a body which flows in streamline motion through a fluid can be expressed by an equation of the type

$$R = \alpha L u \mu \qquad (2)$$

where α is an arbitrary constant which varies with the shape and position of

---

NOTE: Tables A, B, C, and D (experimental K values) which accompany this paper are on file (Document 3495) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting $1.00 for microfilm and $1.35 for photocopies.

† Present address: Westvaco Chemical Division, Food Machinery and Chemical Corp., South Charleston, West Virginia.

TABLE 1(a).—RESISTANCE FUNCTION, δ, FOR SPHEROIDS AS GIVEN BY GANS (7)

$\frac{c}{a}$	For Plates: Proj. Area Elliptical, δ_a	For Plates: Proj. Area Circular, δ_c	For Rods: Proj. Area Circular, δ_a	For Rods: Proj. Area Elliptical, δ_c
0.0	1.767	1.178	∞	∞
0.1	1.631	1.174	3.764	2.617
0.2	1.516	1.160	2.799	2.108
0.3	1.418	1.145	2.367	1.815
0.4	1.335	1.125	1.914	1.606
0.5	1.261	1.105	1.663	1.451
0.6	1.196	1.084	1.467	1.326
0.7	1.139	1.063	1.314	1.224
0.8	1.088	1.041	1.191	1.138
0.9	1.041	1.019	1.091	1.063
1.0	1.000	1.000	1.000	1.000

TABLE 1(b).—SETTLING RATE FACTOR, K, VALUES FOR SPHEROIDS CALCULATED FROM THE DATA OF TABLE 1(a)

$\frac{h}{d} = \frac{c}{a}$ Plates	For Plates: Proj. Area Elliptic, K_a	For Plates: Proj. Area Circular, K_c	For Rods: Proj. Area Circular, K_a	For Rods: Proj. Area Elliptic, K_c	$\frac{h}{d} = \frac{1}{c/a}$ Rods
0.000	0.000	0.000	0.000	0.000	∞
0.100	0.757	0.545	0.809	0.563	10.00
0.200	0.887	0.679	0.957	0.721	5.00
0.250	0.929	0.726	0.994	0.773	4.00
0.300	0.949	0.766	1.016	0.813	3.33
0.333	0.963	0.789	1.028	0.835	3.00
0.400	0.984	0.829	1.039	0.872	2.50
0.500	1.001	0.877	1.047	0.914	2.00
0.600	1.008	0.914	1.043	0.943	1.67
0.700	1.011	0.944	1.037	0.966	1.43
0.800	1.010	0.966	1.025	0.980	1.25
0.900	1.005	0.983	1.016	0.990	1.11
1.000	1.000	1.000	1.000	1.000	1.00

orientation of that particular body, and L is the linear dimension chosen to define the size or projected area of the body.

For a sphere settling with a uniform velocity in viscous motion under the influence of gravity, the net gravitational force, F, may be found from the equation:

$$F = gV'(\rho_s - \rho_f) = g\left(\frac{\pi}{6} d_s^3\right)(\rho_s - \rho_f) \quad (3)$$

At this constant terminal velocity, $F = R$, so that by equating formulas (1) and (3) Stokes' law is obtained:

$$u_s = \frac{g}{18}\left[\frac{d_s^2(\rho_s - \rho_f)}{\mu}\right] \quad (4)$$

This equation is applicable only to the viscous region where the Reynolds' numbers are less than 0.10. It can be derived also by the use of the coefficient of resistance, C_R, which is usually called the drag coefficient. The relation of the drag coefficient with the resistance, R, and the Reynolds' number, Re, is given in Equation (5):

$$C_R = \frac{2R}{A_n \rho_f u^2} = f(Re) \quad (5)$$

These variables are related to each other by dimensional analysis. For a sphere Equation (5) simplifies to the well-known expression

$$C_R = \frac{24}{Re} \quad (6)$$

which is substantiated by a mass of combined data for Reynolds' numbers less than 0.10. Since this present work was restricted to the streamline region, the preceding equations for the sphere were used as a basis for comparison with those of the nonisometric particles tested.

The shape correction factor, K, is defined by the ratio given below:

$$K = \left(\frac{u}{u_s}\right)_V \quad (7)$$

For nonspherical particles it can be found by substituting experimental data in the expression

$$K = \frac{18\eta\mu}{g d_s^2(\rho_p - \rho_f)} \quad (8)$$

The resistance of any free-settling particle may be found by combining Equations (7) and (1) to give

$$R = 3\pi\mu d_s\left(\frac{u}{K}\right) \quad (9)$$

By substituting for R in Equation (5), letting $A_n = A_c$, one obtains

$$C_R = \frac{24}{K}\left(\frac{\mu}{d_s u \rho_f}\right) = \frac{24}{K(Re)} \quad (10)$$

Since the K values are usually less than one, the drag coefficients for the particles are ordinarily more than those for spheres of the same volume. Equation (10) is derived in its simplified form by arbitrarily substituting for A_n in Equation (5) the projected area of a sphere of equivalent volume to the particle. Therefore, the shape correction factor K for the particle when compared to a sphere whose K value is always one, will advantageously show the effects of shape and orientation only.

Gans has listed in a complete table the variation of the resistance function, δ, with changes in the spheroidal shape. The shape correction factor, K, for spheroids can be readily expressed in terms of Gans' function, δ, if the resistance experienced by the spheroid is made equivalent to that of the sphere. Then

$$K_a = \delta_a\left(\frac{d_s}{2a}\right) = \left(\frac{u_a}{u_s}\right)_V \quad (11)$$

when the spheroid is falling in the direction of the half axis a. And

$$K_c = \delta_c\left(\frac{d_s}{2a}\right) = \left(\frac{u_c}{u_s}\right)_V \quad (12)$$

when the direction of fall is parallel to the half-axis c.

Values of these δ functions as evaluated by Gans are given in Table 1(a). For the oblate spheroid (disk) where $a = b > c$,

$$d_s = 2\sqrt[3]{a^2 c},$$

so that

$$K_a = \delta_a\sqrt[3]{c/a} \quad (13)$$

and

$$K_c = \delta_c\sqrt[3]{c/a} \quad (14)$$

For the prolate spheroid (rod) where $a > b = c$,

$$d_s = 2\sqrt[3]{ac^2},$$

so that

$$K_a = \delta_a(c/a)^{\frac{2}{3}} \quad (15)$$

and

$$K_c = \delta_c(c/a)^{\frac{2}{3}} \quad (16)$$

Analytical settling data for cylinders and rectangular parallelepipeds are lacking because of the mathematical complexities involved. However, for very thin disks and long rods, Gans' equations for spheroids may be approximated as follows.

For very thin disks,

$$\delta_a = \frac{9}{16}\pi\left[1 - \frac{8}{3\pi}\left(\frac{c}{a}\right)\right] \quad (17)$$

$$\delta_c = \frac{3\pi}{8} \quad (18)$$

For long rods,

$$\delta_a = \frac{3}{4}\left[2\log_e\left(\frac{2a}{c}\right) - 1\right] \quad (19)$$

$$\delta_c = \frac{3}{8}\left[2\log_e\left(\frac{2a}{c}\right) + 1\right] \quad (20)$$

Comparison of Shape Factors. Many methods have been suggested for classifying irregular particles as to size, shape and roundness (4). For the sedimentation analysis of irregular par-

ticles, the Stokes' diameter is an important measure of particle size. It is determined from the settling velocity of the suspension by means of Stokes' law, Equation (4) except that d_s becomes known as the Stokes' diameter. The relation between the Stokes' diameter and the equivalent volume diameter of an irregular particle may be obtained by the combination of Equations (4) and (8). Thereupon,

$$(d_{ST}/d_s) = \sqrt{K} \qquad (21)$$

This simple equation shows that if particles having small K values are freely settled in a viscous medium, the error in assuming that d_{ST} will approximate d_s may be large. In any attempted correlation of K values, it is apparent that either d_s or d_{ST} will have to be considered. For this study since three-dimensional flow exists for all shapes of particles tested, the equivalent volume diameter, d_e, is used in the calculation of the Reynolds' number and the subsequent correlations.

The sphericity, ψ, is one of the most important factors used when finding the effect of particle shape on the settling velocity. It was originally developed by Wadell (*25*) as

$$\psi = \left(\frac{A_s}{A}\right)_V \qquad (22)$$

where ψ is the degree of true sphericity, which is equal to the ratio of the surface area of the sphere to that of the particle of equivalent volume. Since the measurement of true sphericity is difficult, Wadell (*26*) approximated this parameter by other shape factors which may be found from measurements in two dimensions only, his circularity factor being given below:

$$\text{The degree of circularity} = \phi = \frac{C'}{C} \qquad (23)$$

where C' is the circumference of a circle having the same projected area as the particle, and C is the actual perimeter of this projected area.

Heywood's volume (*10*), shape-factor coefficient is well known as

$$K_H = \frac{V}{d_n^3} \qquad (24)$$

Recent additions to the seemingly unending growth of correlation factors have been advanced by Malaika.

The authors consider the shape factor N, defined below, as one of the most important correlating factors:

$$N = \left(\frac{A}{4A_n}\right)_V \qquad (25)$$

This factor is somewhat similar to Heywood's coefficient, but it is troublesome to evaluate because of the difficulties encountered in measuring the surface area of the particle. After careful examination of these ratios, the three variables d_e, d_n and ψ were selected as those necessary to determine the settling-rate factor K for a given position of orientation. A general correlation based on this minimum number of defining variables was the ultimate purpose of the experimental work which followed.

TABLE 2(a).—DIMENSIONS AND PHYSICAL PROPERTIES OF ORIGINAL BAR STOCKS FROM WHICH PARTICLES WERE MADE

Round Bar Stock

Material	Nominal diam. in.	Density g./ml.
Aluminum	1/8	2.7691
Aluminum	5/32	2.7825
Aluminum	3/16	2.7783
Aluminum	7/32	2.7864
Aluminum	1/4	2.7847
Aluminum	5/16	2.7905
Aluminum	3/8	2.7902
Brass	3/32	8.5007
Brass	1/8	8.3844
Brass	7/32	8.4972
Steel	0.0625	7.7811
Steel	0.0747	7.7890
Steel	0.0878	7.7864
Steel	0.1006	7.7770
Steel	0.1092	7.7802
Steel	0.1251	7.7730
Steel	0.1405	7.7955

Square Bar Stock

Material	Nominal length of side, in.	Density g./ml.
Aluminum	1/16	2.7140
Aluminum	1/8	2.7769
Aluminum	3/16	2.7844
Aluminum	1/4	2.8042
Aluminum	5/16	2.6980
Aluminum	3/8	2.8036
Brass	1/16	8.4857
Brass	1/8	8.9912
Brass	3/16	8.5303
Brass	1/4	8.5037
Brass	5/16	8.5164
Steel	3/64	7.7114
Steel	1/16	7.7479
Steel	5/64	7.7752
Steel	3/32	7.7923
Steel	7/64	7.7710
Steel	9/64	7.7896
Steel	5/32	7.7919

Description of Apparatus

Preparation of the Particles. Since adequate, experimental data were unavailable for cylinders and rectangular parallelepipeds when settling in two positions of orientation, a wide variety of these shapes was made and tested. These particles all possessed three perpendicular symmetry planes, and were expected to settle in the position of initial orientation, as proved mathematically by Gans. The maximum volume of each shape of particle to be prepared was originally set as that equivalent to a ¼-in. sphere. The limitation on size was determined by the maximum wall factor allowed for the particles by the authors, but in a number of cases it was exceeded because of the scarcity of the smaller sizes of bar stock used as the raw material. Cylinders and rectangular parallelepipeds with h/d ratios of ¼, ½, 1, 2, 3, and 4 were made with at least five different sizes being selected for each shape. Round and square bar stock of aluminum, brass, and steel drill rod were used as the materials. Table 2(a) lists the dimensions and physical properties of the original bar stock.

A rather unique method of manufacturing these particles in quantity is described by Heiss (*8*) and Beroes (*2*). Since the smaller particles were difficult to produce accurately, and to duplicate individually by means of a lathe, the method developed was advantageous to all others in that a large number of duplicates of a given shape could be produced, whose deviations in weights and dimensions were extremely small. At the beginning of this process, oversize particles of a given shape with one surface-ground base were placed with polished faces downward on the steel disk of a Buehler mounting press. The particles were then mounted in lucite similar to specimens about to receive polishing for metallographic examination. If the indicated temperature of the press was kept below 160° C., fine mounts were obtained. However, if the indicated temperature exceeded 160° C., the lucite became very fluid so that the particles tended to float, coming off the base of the disk and leaning inward toward the center so that the mount would have to be discarded. This happened only with the smaller particles, less than ⅛ in. in diameter.

After the plastic mount had been made, it was placed in a special chuck (*8*), and the particles were carefully and slowly ground to size by a disk grinder. The method later adopted (*2*) was that of turning the lucite disk to size on a South Bend precision lathe. In either case the grinding or turning had to be done slowly, with adequate cooling; otherwise the particles would overheat and drop out of the plastic. With the proper technique and patience, however, the particles were ground down to within at least ±0.001 of an inch of the desired length. All duplicates, regardless of size, weighed within at least one half of a per cent of each other when made by this method. Most of the particles of h/d ratios less than one, especially the smaller sizes, had to be made in this way.

Aluminum and chrome-alloy steel spheres were used in determining the viscosity of the fluids by the falling-sphere method. For aluminum, the spherical tolerance of 0.0002 of an inch is about the best one can expect because of the softness of the metal. The high carbon, chrome-alloy steel balls, grade number two, had a sphericity of 0.00005 of an inch. Data on the physical properties of these spheres are given in Table 2(*b*).

Determination of Densities. For the steel spheres the density was calculated directly from the averaged weight of 12 spheres, determined by an analytical, "chainamatic" balance accurate to 0.0001 of a gram while the average diameter was measured by a new, Starret 0-1 in. micrometer, reading to the nearest 0.0001 of an inch. The aluminum spheres were so soft that it was difficult to obtain a reliable value of the diameter by the micrometer even with the rachet type of adjustment. Therefore, the densities of the aluminum spheres and of all the other particles were obtained by displacement in two different liquids. Since the majority of the particles used was of steel, chloroform and tetrachloroethane, high density displacement liquids were satisfactory in giving a larger loss in weight than would water. An analytical, "chainamatic" balance, with a slotted glass basket attached to one arm to hold the particles when immersed in the liquid, was used for all the determinations. No effort was made to control the temperature of the liquid. It

TABLE 2(b).—DATA ON PHYSICAL PROPERTIES OF SPHERES USED TO OBTAIN THE VISCOSITY

Material	Nominal Diam. in.	Actual Diam. cm.	Average weight g.	Density g./ml.
Aluminum	1/8	0.3180	0.0457	2.7150
Aluminum	5/32	0.3965	0.0916	2.8070
Chrome Iron	1/8	0.3167	0.1300	7.8173

TABLE 3.—INTERCEPT VALUES OF SETTLING RATE FACTOR, K, FOR CYLINDERS AND RECTANGULAR PARALLELEPIPEDS

	Cylinders		Rectangular Parallelepipeds	
$\frac{h}{d}$	$K_{\text{Roundside}}$	K_{Flatside}	$K_{\text{Rectangular Proj. Area}}$	$K_{\text{Square Proj. Area}}$
0.25	0.915	0.762	0.868	0.717
0.50	0.961	0.864	0.935	0.844
1.00	0.945	0.958	0.926	0.926
2.00	0.878	0.975	0.862	0.963
3.00	0.807	0.958	0.816	0.971
4.00	0.758	0.929	0.760	0.920

was measured at the time of the determination and then the density of the liquid was obtained from a graph of density vs. temperature. Density data for these graphs were obtained by using a Fisher chain gravitometer, accurate to ±0.0005 g./ml. For the smaller particles the displacement method was not sufficiently accurate so that several pieces of the original bar stock were used, giving a reasonable loss in weight which could be measured on the balance. The deviation of the particle densities calculated by displacement in these two different liquids was usually 0.2 of a per cent or less for all sizes of particles. The average of these two values constitutes the value of each density used throughout the experiments.

Various Fluids Used. Preliminary calculations indicated that a fluid with an absolute viscosity of approximately 20 poises would be adequate to insure streamline settling of all the particles (Re<0.10). Since the container would have to be open at the top to allow for manual orientation of the particles, the fluid chosen must not be hygroscopic, must not react physically or chemically with the atmosphere and must not be concentrated by evaporation. Originally, glycerine was used with a new viscosity being calculated daily by the falling-sphere method. However, a film of water eventually collected at the top of the column and 'Schlieren' lines were visible as the particles dropped through the fluid. With Arlex, a commercial sorbitol solution, a similar effect was apparent.

The fluid used for the majority of these runs came from the Ucon series supplied by the Carbide and Carbon Chemicals Co. These fluids which are made from polyalkylene glycols and their derivatives have comparatively little change in viscosity with temperature, obtain their equilibrium water content within one day and are relatively stable in their physical properties thereafter. The particular Ucon fluid used in these experiments was of the water-soluble type, 50-HB-6200.

Densities of all the sedimentation fluids were determined with 25 ml. pycnometers by conventional methods. Determinations were made in triplicate with an average deviation of one part in ten thousand. The density of the Ucon fluid, which remained in the open container for several weeks during the settling experiments, was found to be substantially constant during this period at 1.0543 g./ml. at 31.4° C.

Viscosities of the fluids were found by the falling-sphere method. This method is oftentimes suggested when determining viscosities greater than 10 poises, but the correction for wall effect must be chosen carefully. After a thorough comparison of the wall-effect equations proposed by Ladenburg (*13*), Faxen (*5*), and Francis (*6*) together with Faxen's (*20*) revised form of the Ladenburg equation, it was apparent that for ratios of sphere diameter to container tube diameter less than 0.06, all these equations except the final one mentioned gave results which varied less than one half of one per cent from one another. Experimental data on spheres accumulated by the authors to check these formulas substantiated the first three equations. Faxen's modification of the original Ladenburg equation should be avoided, even though used by many previous investigators, unless additional data prove its accuracy. For this work any of the initial three equations may be used since low Reynolds' numbers and small d_s/D ratios are encountered. The Ladenburg equation given below was chosen chiefly because of its simple form:

$$(u_s)_\infty = u_s\left[1 + 2.4\frac{d_s}{D}\right] \qquad (26)$$

Constant Temperature Bath. The particles were settled in an open, 2-l. graduated cylinder of 7.09 cm. average I.D., being timed manually between two graduations, 35.61 cm. apart. A screen with a hollow eye attached lay on the bottom of the cylinder so that the particles could be reclaimed easily for future runs. An annular screen attached to the top of the graduate held the particles for several hours prior to each series of runs.

The two-liter cylinder was clamped in a perfectly vertical position inside a Pyrex jar, 24 in. high with an 11¼-in. I.D. so that the top of the two-liter cylinder was practically flush with the top of the jar. The temperature of the water bath was intentionally maintained at 31.4° C., which during the summer months was usually a few degrees above the room temperature. A cooling coil was immersed in the bath as a precautionary measure should the room temperature exceed 31.4° C. Since the bath was operated at substantially room temperature, little heat input was needed, and the temperature control was excellent.

The temperature control equipment consisted of a No. 9926D Infra-Red Constant Temperature Bath, Research Model.* This unit controlled the temperature to at least ±0.01° C. No immersion heaters were used, the only source of heat being radiant from the 250-w. infrared lamp so that practically no temperature lags were encountered. A top plate of plastic on the bath held a radiant shield, a stirring motor and a thermoregulator of the mercury type. An additional "laboratory stirrer" was added to increase the circulation. A calibrated −5° C. to 50° C. thermometer, graduated in 0.1° C. divisions, was used in measuring the bath temperature. Two 25-w. amber lights were placed in such a way that the desired graduations on the cylinders could be clearly seen when timing the particles. A further description of this apparatus follows.

Experimental Procedure

The constant temperature bath was put into operation at least eight hours before experiments were to be conducted. Actual time-temperature curves proved that at least four to six hours were required for the viscous liquid to come to equilibrium at a uniform temperature of 31.4° C. In many cases the bath was operated continuously for long periods of time with no shutdowns.

A wide variety of sizes of one particle shape was placed on the screen together with 12 of each of the ⅛-in. and 5/32-in. diam. aluminum spheres a few hours before the experiments were to be made. When the sedimentation fluid was definitely at equilibrium at 31.4° C., six ⅛-in. spheres and six 5/32-in. spheres were dropped through the center of the guide and timed between the two specified graduations with an Elgin 10-sec. sweep stop watch, graduated in 0.1-sec. divisions. Then the particles were oriented manually, either in their stable settling position or perpendicular to that position and were released from tweezers through the guide in the top screen. Smaller sizes causing less disturbance of the fluid were dropped first. After all the particles had been dropped,

TABLE 4.—SETTLING DATA FOR CYLINDER

$h = d$, oriented roundside

Fluid — Ucon, 50-HB-6200
Viscosity — 20.17 g./(cm.)(sec.)
Density — 1.0543 g./ml.

Nominal Diam. d, in.	Equivalent Diam., d_s, cm.	Material	Vel., u, cm./sec.	Settling Factor K	$Re = \frac{d_s u \rho}{\mu}$	Coefficient of Resistance $C_{D_{actual}}$	Coefficient of Resistance C_{D_∞}
0.0625	0.1814	Steel	0.536	0.896	0.00508	5273.	5000.
0.0747	0.2181	Steel	0.761	0.879	0.00868	3147.	2927.
0.0878	0.2551	Steel	1.031	0.871	0.0137	2004.	1847.
0.0914	0.2656	Brass	1.226	0.864	0.0170	1632.	1492.
0.1008	0.2937	Steel	1.342	0.857	0.0206	1360.	1233.
0.1092	0.3180	Steel	1.556	0.847	0.0259	1096.	982.3
0.1251	0.3639	Steel	2.016	0.839	0.0354	746.2	662.5
0.1254	0.3640	Aluminum	0.513	0.836	0.00976	2944.	2604.
0.1405	0.4085	Steel	2.502	0.823	0.0534	545.6	475.2
0.1568	0.4552	Aluminum	0.782	0.808	0.0186	1594.	1363.
0.1869	0.5427	Aluminum	1.072	0.782	0.0304	1010.	835.8
0.2182	0.6345	Aluminum	1.427	0.757	0.0473	669.7	536.5
0.2502	0.7264	Aluminum	1.793	0.727	0.0681	484.9	373.0

*Arthur H. Thomas Co., Philadelphia, Pa.

the viscosity was rechecked by settling six ⅛-in. aluminum spheres and six 5/32-in. aluminum spheres. The average viscosity calculated from the ⅛-in. spheres usually agreed to within 0.2% with the viscosity calculated from the 5/32-in. spheres or from ⅛-in. chrome-alloy steel balls. If a large number of particles was settled, tiny air bubbles would begin to form in the center of the stream. Check runs at the end of the experiments proved that the effect of these minute air bubbles was negligible.

Since some smaller particles might not settle exactly in the center of the tube because the guide through which they passed was ½ in. in diameter, this off-center effect on velocity was questioned. Tests were made with 3/16-in. spheres falling as much as ½ in. away from the center. The decrease in velocity from the value at the center was only 0.4% for this rather large size so that this effect was considered negligible thereafter.

The timing of a group of particles of a given shape and size was considered reliable when the deviation between the high and low extreme values was no more than one per cent of the absolute value of the time. If the orientation appeared perfect when observed, it was oftentimes possible to check the velocities on duplicates to better than 0.5%. With a small amount of practice, it was readily possible to manipulate the particle to the desired position of orientation. Only in the case of the $d/4$ shape, falling in its stable position, did the particle move from the center of the tube on its downward path. For this shape the large sizes did not "drift," but the ⅛-in. and 5/32-in. sizes because of inaccuracies of construction, probably, drifted towards the wall.

Many different individuals checked the timing of these particles for the two types of orientation so that there would be no personal error involved. Usually, at least 12 droppings on any one size and shape were made. The velocity, in general, was considered to be accurate within at least ±1%.

Experimental Results

After the settling velocities for a particle of a given size and shape had been duplicated in the two positions of orientation, its shape correction or settling rate factors were calculated. These K values included shape, orientation, and wall effects. To eliminate the wall effect and to find the shape and orientation effects only for the particle settling in an infinite medium, the method used by Pettyjohn and Christiansen for isometric particles was selected. This method appeared to be more accurate than that of using a wall-effect equation for spheres and extrapolating the individual K values to a particle diameter of zero. In applying Pettyjohn's method of plotting K vs. d_s and extrapolating to d_s equals zero to find K_∞ corrected for wall effect, it was necessary to use small sizes of each particle shape in order to avoid an excessive extrapolation. The ratio of d_s/D rarely exceeded 0.1 as a maximum so that straight line plots of K vs. d_s, which were excellent for extrapolation purposes, were always obtained.

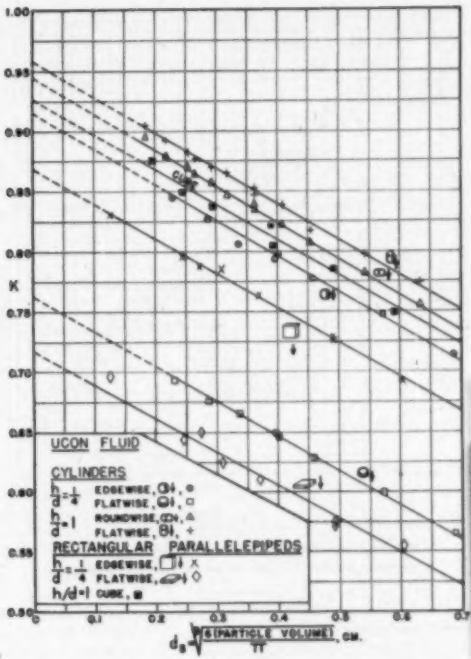


Fig. 1. Settling factor K plotted as a function of the equivalent spherical diameter for some typical runs in the 7.09-cm. diam. cylinder.

A typical graph of shape correction factor K vs. d_s for cylinders and rectangular parallelepipeds of shapes $h = d/4$, and $h = d$ is shown in Figure 1. For the cylinders or the rectangular parallelepipeds the distances between the two respective straight lines for one shape represents the variation in K caused by orientation. As the particles approach that shape where $h/d = 1$, the differences between these two straight lines for cylinders become small, whereas only one line is obtained for the cube whose settling rate is unaffected by orientation.

Values of the shape correction factor K_∞, corrected for wall effect, were obtained from a series of these K vs. d_s plots. Heiss used the "method of averages" for finding the intercept K_∞ values for cylinders while Beroes chose the "method of least squares" for his work on rectangular parallelepipeds. Beroes' K_∞ value for a cube agreed to within 0.4% of that found by Pettyjohn in much larger settling columns, which was considered to be indication that the results obtained from this smaller column were satisfactory. Table 3 lists these extrapolated settling factors as a function of shape and orientation. The K_∞ values for spheroids, as calculated from the δ resistance functions of Gans, are given for comparison in Table 1(b). A typical plot of the coefficient of resistance vs. Reynolds' number is shown in Figure 2 for cylinders. Since the intercept K_∞ values are the only ones of importance, the other experimental K values are not listed here* except in Table 4 where the average data of a number of settling runs for the cylindrical particle shape ($h = d$) are tabulated.

Correlation of Data

The effect of the particle shape on the settling factor K_∞ may be observed from the experimental data plotted in Figure 3. A comparison of the experimental data for cylinders and rectangular parallelepipeds with the theoretical K_∞ values for spheroids is given in the same figure. As the particles become rodlike in shape, the K_∞ vs. h/d curves for cylinders and rectangular parallelepipeds approach the curves for spheroids as asymptotes. However, the curves for disks with small h/d ratios cross over the curves for spheroids, instead of becoming asymptotic with them. Unpublished data (3) show that these curves for disks do become asymptotic, as would be expected, with those for spheroids when the h/d ratios approach zero.

The effect of orientation on the settling factor K_∞ may be seen from Figure 4, which is derived from the data of Figure 3. The independent variable, ΔK_∞, represents the difference of the settling factors in the unstable- and

* See footnote on p. 133.

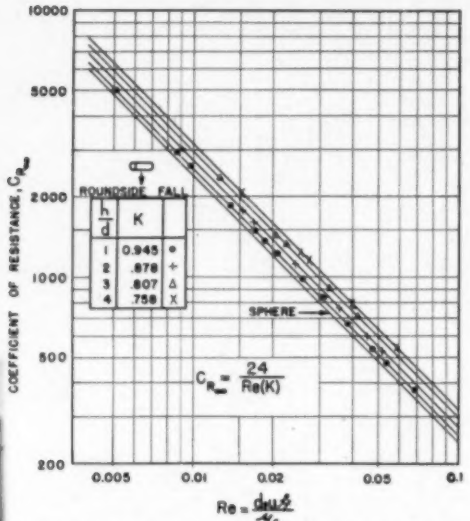


Fig. 2. Coefficient of resistance (corrected for wall effect) vs. the Reynolds number for four cylindrical, particle shapes.

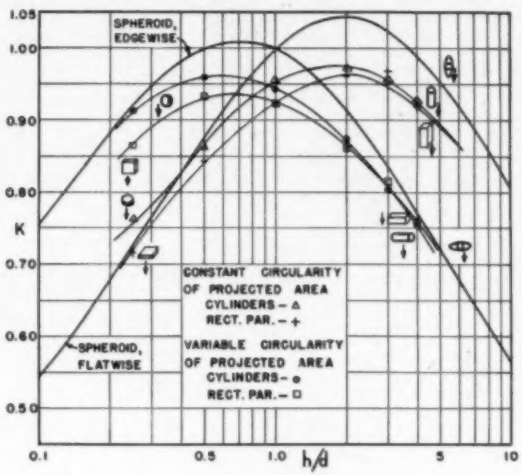


Fig. 3. Settling factor K_∞ plotted as a function of height-diameter ratio for cylinders, rectangular parallelepipeds, and spheroids.

stable-settling positions for a particular shape of particle. Therefore, ΔK_∞ is always positive, increasing as the particle shape departs from isometric proportions.

If the sedimentation method is to be used in finding the average particle size of an infinitely dilute suspension, the correction for shape and orientation effects may be applied from Equation (21). However, assumptions of the average particle shape and average settling factor must be made.

The sphericity was assumed to be one of the most important variables affecting the settling factor, K_∞, because of the similarity of the ψ vs. h/d plot, Figure 5, with that of the K_∞ vs. h/d plot (i.e., shown in Figure 3). However, plots of K_∞ vs. ψ did not correlate, but were of the type shown in Figure 6 for the cylinder. The effect of orientation is plainly evident from the spread of the K_∞ values for individual ψ values.

Heywood's shape factor, K_H, was next examined as a possible correlating factor. The variable d_s/d_n may be obtained by taking the cube root of Heywood's factor or the square root of the authors' N factor. Since the d_s/d_n factor was easy to visualize and to evaluate, it was used as a correlating factor thereafter. A graph of the experimental and analytically determined K_∞ values as a function of d_s/d_n is shown in Figure 7 in which each curve exhibits a maximum. A general correlation was, therefore, expected in which a similar group of curves would be obtained with the sphericity as a parameter. After treatment of the data by empirical methods, the following equations were developed:

$$\log_{10}(K_\infty) = \left[-0.25 \sqrt{\psi \frac{d_s}{d_n}} \left(\frac{d_s}{d_n} - 1 \right) + \log_{10}\left(\frac{d_s}{d_n} \sqrt{\psi} \right) \right] \qquad (27)$$

for orientations where the circularity of the projected area varies as the shape changes, and

$$\log_{10}(K_\infty) = \left[\frac{-0.270}{\sqrt{\psi} \left(\frac{d_s}{d_n} \right)^{0.345}} \left(\frac{d_s}{d_n} - 1 \right) + \log_{10}\left(\frac{d_s}{d_n} \sqrt{\psi} \right) \right] \qquad (28)$$

where the circularity is constant, and does not vary as the shape of the particle changes. Three variable plots of these equations are shown graphically in Figure 8. A comparison of the observed K_∞ values with the calculated K_∞ values from Equations (27) and (28) is given in Table 5. Good agreement of the observed and the calculated values is obtained except for the cylindrical rods in their unstable settling position. Since these K_∞ values are close to 1.00, this deviation is of little importance.

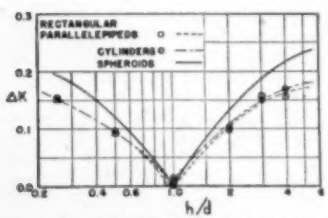


Fig. 4. Effects of orientation and particle shape on the difference of settling factor K_∞.

Summary

The effect of orientation and shape on the settling rates of individual cylinders, rectangular parallelepipeds, and spheroids in the viscous region can be predicted from the general correlation shown graphically in Figure 8. This correlation should prove valuable when dealing with a wide variety of particle shapes. It will prove useful in the design and operation of classification equipment, if correction factors are applied for flocculation effects when hindered settling occurs with suspensions.

The free-settling velocity is determined principally by the position of orientation, the sphericity, and the h/d or d_s/d_n ratio of the particle. As the particle deviates from a shape of isometric proportions, the effect of orientation increases.

The coefficient of resistance is found to vary in similar manner to that of a sphere and may be calculated readily by use of the particle settling factor K_∞.

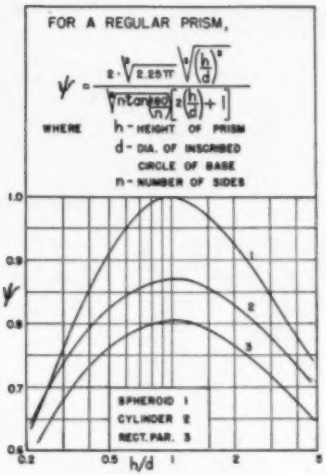


Fig. 5. Sphericity of a prism plotted as a function of height to diameter ratio.

Acknowledgments

Thanks are expressed to Charles S. Beroes, who collected the experimental data on the rectangular parallelepipeds; to Stanley J. Porter, graduate student, who checked the calculations on the final correlation, and to the Carbide and Carbon Chemicals Co. who donated the Ucon fluid used in the experiments.

Notation

a = largest semi-axis of an ellipsoid
A = surface area of the particle, sq.cm.
A_V = projected area of a sphere of same volume as particle, sq.cm.
A_n = projected area of particle, sq. cm.
A_s = total surface area of a sphere of same volume as particle, sq.cm.
b = one of semi-axes of an ellipsoid
c = one of semi-axes of an ellipsoid
C = actual perimeter of a particle of projected area A_n, cm.
C' = circumference of a circle having the same projected area as particle, cm.
ϕ = degree of circularity = C'/C, dimensionless
C_R = coefficient of resistance $= \dfrac{2R}{A_V \rho_f u^2}$ dimensionless
d = diameter of a cylindrical particle, or inscribed diameter of a square, cm. or in.
d_n = diameter of a circle of an area equal to projected area, A_n, of particle, cm.
d_{ST} = equivalent sedimentation diameter of a particle as calculated by Stokes' law, cm.
d_v = diameter of a sphere of volume equivalent to particle, cm.
D = diameter of a cylindrical container, cm.
F = frictional force against a particle, or the net weight of a particle in a fluid medium, dynes
g = acceleration of gravity, 980.7 cm./(sec.)(sec.)
h = height or length of a cylindrical particle, cm. or in.
K = settling rate factor u/u_s at constant volume, dimensionless
K_H = Heywood's volume coefficient $= V/d_n^3$, dimensionless
L = symbol for length, cm.
N = ratio of A/A_n for a particle, divided by same ratio for a sphere of same volume

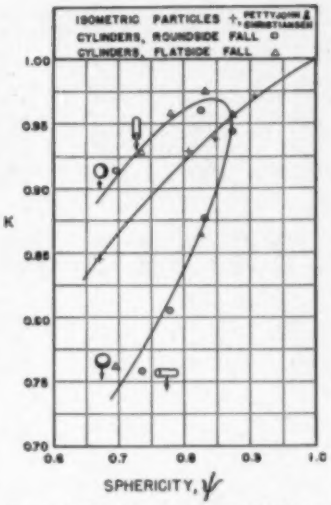


Fig. 6. Settling factor K_α for cylindrical particles plotted as a function of sphericity.

R = frictional resistance against a particle, dynes
Re = Reynolds' number $= \dfrac{d_n u \rho_f}{\mu_f}$ dimensionless
u = free-settling velocity of any particle, cm./sec.
u_s = free-settling velocity of sphere, cm./sec.
$u_{s\infty}$ = free-settling velocity of sphere in an infinite medium, cm./sec.
V = volume of particle, cc.

GREEK:

α = pure number, dimensionless

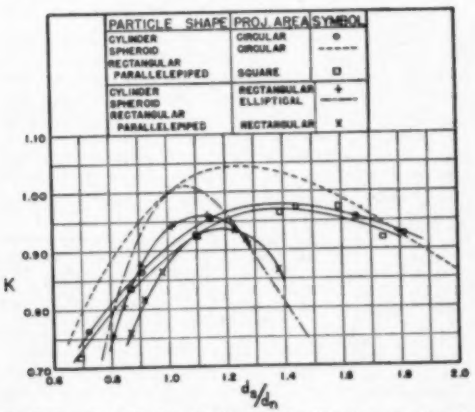


Fig. 7. Experimentally determined values of settling factor K_α plotted as a function of d_s/d_n.

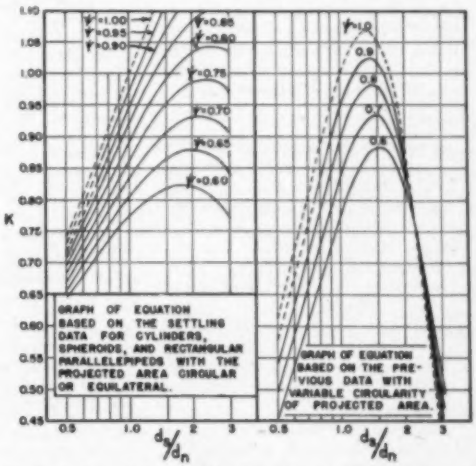

GRAPH OF EQUATION BASED ON THE SETTLING DATA FOR CYLINDERS, SPHEROIDS, AND RECTANGULAR PARALLELEPIPEDS WITH THE PROJECTED AREA CIRCULAR OR EQUILATERAL.
GRAPH OF EQUATION BASED ON THE PREVIOUS DATA WITH VARIABLE CIRCULARITY OF PROJECTED AREA.
K
d_s/d_n

Fig. 8. Final correlation of settling factor K_α plotted as a function of d_s/d_n with sphericity ψ as parameter.

TABLE 5.—COMPARISON OF THE EXPERIMENTALLY DETERMINED SETTLING RATE FACTORS WITH THOSE CALCULATED FROM EQUATIONS (37) AND (38) FOR CYLINDERS, RECTANGULAR PARALLELEPIPEDS AND SPHEROIDS

Cylinders

		Roundside Fall				Flatwise Fall			
h/d	ψ	d_s/d_n	$K_{obs.}$	$K_{calc.}$	% Dev.	d_s/d_n	$K_{obs.}$	$K_{calc.}$	% Dev.
0.25	0.695	1.276	0.915	0.917	0.2	0.721	0.762	0.759	0.4
0.50	0.825	1.138	0.961	0.957	0.4	0.909	0.864	0.881	2.0
1.00	0.873	1.014	0.945	0.941	0.4	1.145	0.958	0.976	1.9
2.00	0.891	0.903	0.878	0.865	1.5	1.443	0.975	1.009	3.5
3.00	0.778	0.844	0.807	0.800	0.9	1.651	0.958	0.989	3.2
4.00	0.734	0.805	0.758	0.752	0.8	1.817	0.939	0.961	3.4
					0.7 Ave.				2.4 Ave.

Rectangular Parallelepipeds

		Projected Area Rectangular				Projected Area Square			
h/d	ψ	d_s/d_n	$K_{obs.}$	$K_{calc.}$	% Dev.	d_s/d_n	$K_{obs.}$	$K_{calc.}$	% Dev.
0.25	0.640	1.385	0.868	0.867	0.1	0.692	0.717	0.727	1.4
0.50	0.762	1.233	0.935	0.930	0.5	0.873	0.844	0.836	0.9
1.00	0.807	1.099	0.926	0.934	0.9	1.099	0.926	0.925	0.1
2.00	0.767	0.979	0.862	0.867	0.6	1.385	0.963	0.949	1.5
3.00	0.719	0.915	0.816	0.806	1.2	1.585	0.971	0.933	4.0
4.00	0.677	0.872	0.760	0.757	0.4	1.744	0.926	0.903	1.8
					0.6 Ave.				1.7 Ave.

Spheroids

		Projected Area Elliptical				Projected Area Circular			
h/d	ψ	d_s/d_n	K^*	$K_{calc.}$	% Dev.	d_s/d_n	K^*	$K_{calc.}$	% Dev.
0.100	0.417	1.466	0.757	0.768	1.5	0.464	0.545	0.588	7.9
0.200	0.625	1.307	0.887	0.881	0.7	0.585	0.679	0.686	1.0
0.300	0.761	1.222	0.949	0.943	0.6	0.669	0.766	0.766	0.0
0.400	0.852	1.166	0.984	0.978	0.6	0.737	0.829	0.828	0.1
0.500	0.913	1.123	1.001	0.999	0.2	0.794	0.877	0.876	0.1
0.600	0.952	1.089	1.008	1.009	0.1	0.845	0.914	0.915	0.1
0.700	0.976	1.062	1.011	1.012	0.1	0.888	0.944	0.944	0.0
0.800	0.991	1.038	1.010	1.010	0.0	0.928	0.966	0.967	0.1
0.900	0.998	1.018	1.005	1.006	0.1	0.965	0.983	0.985	0.2
1.000	1.000	1.000	1.000	1.000	0.0	1.000	1.000	1.000	0.0
1.111	0.999	0.982	0.990	0.992	0.2	1.036	1.016	1.013	0.3
1.250	0.991	0.963	0.980	0.978	0.2	1.077	1.025	1.023	0.2
1.429	0.979	0.943	0.966	0.964	0.2	1.126	1.037	1.033	0.4
1.667	0.959	0.918	0.943	0.939	0.4	1.186	1.043	1.039	0.4
2.000	0.928	0.891	0.914	0.908	0.6	1.260	1.047	1.039	0.8
2.500	0.885	0.858	0.872	0.866	0.7	1.357	1.039	1.033	0.6
3.333	0.823	0.818	0.813	0.808	0.6	1.494	1.016	1.009	0.7
5.000	0.732	0.765	0.721	0.725	0.6	1.710	0.957	0.954	0.3
10.000	0.590	0.681	0.563	0.588	4.4	2.154	0.809	0.808	0.1
					0.6 Ave.				0.7 Ave.

* Obtained from the analytical equations of Gans (7). For the shapes h/d equal ¼ and 4, the K values have been checked experimentally by Malaika (15).

δ = measure of resistance of an ellipsoid, dimensionless
μ = viscosity, poises, g./(cm.)(sec.)
ρ_f = density of fluid, g./ml.
ρ_p = density of particle, g./ml.
ψ = true sphericity = ratio of surface area of sphere, of same volume as particle, to that of particle, dimensionless

SUBSCRIPTS:

a = position of orientation of ellipsoid where axis a is in direction of motion
c = position of orientation of ellipsoid where axis c is in direction of motion
f = pertaining to fluid
n = pertaining to projected or normal area
p = pertaining to particle
s = pertaining to a sphere
V = pertaining to constant volume
∞ = pertaining to an infinite medium

Literature Cited

1. Bairstow, L., Cave, B. M., Lang, E. D., *Phil. Trans. A*, **223**, 383 (1923).
2. Beroes, C. S., "The Effect of Shape and Orientation on the Free Settling Rates of Square Plates and Bars in a Viscous Medium," M.S. Thesis, University of Pittsburgh, pp. 17-20 (1950).
3. Brahma, P. C., "The Effect of Orientation and Thickness on the Free Settling Rates of Thin Disks in a Viscous Medium," M.S. Thesis, University of Pittsburgh, pp. 24-30 (1950).
4. Dallavalle, J. M., "Micromeritics," Second ed., pp. 47, 48, Pitman Publishing Co., New York (1948).
5. Faxen, H., *Arkiv för Mat, Astron Fysik*, **17**, No. 27, 1 (1923).
6. Francis, A. W., *Physics*, **4**, 403 (1933).
7. Gans, R., *Sitzber math-physik Klasse Akad Wiss München*, **41**, p. 198 (1911).
8. Heiss, J. F., "The Effect of Orientation on the Settling Velocity of Disks and Rods in a Viscous Medium," Ph.D. Dissertation, University of Pittsburgh, pp. 28-33 (1950).
9. Heywood, H., *Proc. Inst. Mech. Engrs.* (London), **140**, 257 (1938).
10. Heywood, H., *Chemistry & Industry*, **56**, Part 2, 149 (1937).
11. Krumbein, W. C., *Am. Geophysical Union*, 626 (1942).
12. Kunkel, W. B., "Magnitude and Character of Errors Produced by Shape Factors in Stokes' Law Estimates of Particle Radius," *J. Applied Physics*, **19**, No. 11, 1056 (1948).
13. Ladenburg, R., *Ann. Phys.*, **23**, p. 447 (1907).
14. Lamb, H., *Hydrodynamics*, Sixth ed., Article 342, p. 610, Dover Publications, New York (1945).
15. Malaika, J., "Effect of Shape of Particles on Their Settling Velocity," Ph.D. Dissertation, State University of Iowa, Iowa City, pp. 11-13 (1949).
16. Oberbeck, H. A., *Crelles J.*, **81**, 79 (1876).
17. Pernolet, V., *Ann Mines*, 4me. Serie, XX, p. 379, 535 (1851).
18. Perry, J. H., "Chemical Engineers' Handbook," Second ed., p. 1853, McGraw-Hill Book Co., Inc., New York (1941).
19. Pettyjohn, E. S., and Christiansen, E. B., *Chem. Eng. Progress*, **44**, No. 2, 171 (1948).
20. Schiller, L., "Handbuch der Experimentalphysik," Bd. IV, Teil 2, p. 343 (1932).
21. Schmiedel, J., *Physik. Z.*, **29**, 593 (1928).
22. Schultz, P., *Glückauf*, **51**, 458 (1915).
23. Squires, L., and Squires, W., Jr., *Trans. Am. Inst. Chem. Engrs.*, **33**, 1 (1937).
24. Stokes, G. G., *Trans. Cambridge Phil. Soc.*, **9**, Part II, 51 (1851).
25. Wadell, H., *J. Franklin Inst.*, **217**, 459 (1934).
26. Wadell, H., *J. Geol.*, **41**, 310 (1933).
27. White, C. M., *Proc. Roy. Soc., A*, **186**, 472 (1946).
28. Wieselsberger, C., *Physik. Z.*, **23**, 219 (1922).

EVAPORATION FROM DROPS

Part I

W. E. RANZ* and W. R. MARSHALL, JR.

University of Wisconsin, Madison, Wisconsin

An investigation was made of the factors influencing the rate of evaporation of pure liquid drops, and the rate of evaporation of water drops containing dissolved and suspended solids. The study was restricted to a Reynolds number range of 0 to 200, the range usually encountered in spray-drying operations. Independent correlations of heat- and mass-transfer rates were obtained from drop temperatures measured with 0.5 mil thermocouples. Drop diameters ranged from 0.06 to 0.11 cm., and air temperatures up to 220° C.

Results of studies on pure liquid drops confirmed the analogy between heat and mass transfer at low Reynolds numbers, and verified the simple expression for the Nusselt number at zero Reynolds number. A general correlation of existing data on spherical particles showed the results of this study could be extrapolated with remarkable accuracy five times beyond the experimental range of Reynolds numbers.

Studies on water drops containing dissolved and suspended solids furnished a preliminary insight into the mechanism of the formation of particles dried from drops. The results showed that when the solid was in solution the drop evaporated initially as though it were saturated throughout, even though its average concentration was less than saturation. This was shown to be true for solutions of ammonium nitrate and sodium chloride, and a convenient method for estimating the drop temperature and evaporation rate for this case was proposed. For drops containing insoluble materials, the initial evaporation rate was found to correspond to that for pure water. When the drop formed a solid structure and its diameter became constant, the falling-rate period ensued during which the drop temperature rose continually. This temperature rise was due to both heat of crystallization and sensible heat transfer, in the case of solutions, and primarily to sensible heat transfer in the case of suspensions.

METHODS of predicting the evaporation rates of a single drop and the phenomena associated with the evaporation process are of importance in the analysis of chemical engineering operations involving dispersions in gases. Fundamental data on the factors affecting the rate of heat and mass transfer for a spray droplet are important to the operations of spray drying, spray cooling, humidification, spray absorption, spray extraction, combustion, crystallization, dissolution, transfer in fluidized beds, and any other operation where transfer occurs between a continuous phase and a discontinuous phase which appears as spherical particles.

The purpose of this paper is to report a fundamental study of evaporation from drops. This study was divided into the following parts:

1. Rate of heat transfer to the drop surface.
2. Rate of evaporation and mass transfer from the drop surface.
3. Temperature and concentration at the drop surface during evaporation.
4. Effect on evaporation rate of original drop temperature, heats of solution and crystallization, and the way in which solid surfaces form.

Application of the results has been made with specific reference to spray drying. In spray drying, as in most drying problems, the first period of drying, usually termed the constant-rate period, is susceptible to a simple analysis. However, as soon as a spray droplet concentrates to the point where it no longer presents a free liquid surface to the gas stream, it becomes a particle with drying characteristics determined by the nature of the solid structure. The particle then enters a period in which the rate of drying decreases with decreasing moisture content. For application to the operation of spray drying, this study was primarily concerned with the constant-rate period.

Review of Previous Work

Only a small amount of experimental work has been done on the fundamentals of heat and mass transfer in the evaporation of single drops. Experimental difficulties are evident when it is realized that drop diameters should be in the range of 200 to

* Present address: University of Illinois, Urbana, Ill.

800μ, and the Reynolds number range should be from 0 to 100 to approach conditions of commercial interest.

Kramers (*17*) recorded heat-transfer data for spheres in the low Reynolds number range. However, the diameters of the spheres he used were of the order of 1 cm., and free convection obscured the true effect of the velocity of the fluid stream. Meyer (*23*) presented an analysis of data on free convection from spheres in quiescent fluids of various kinds.

Evaporation of solid and liquid drops in still air has been treated from the standpoint of simple mass transfer. Experimental data of Morse (*24*) on the sublimation of iodine beads led to a calculation by Langmuir (*18*) of the diffusivity of iodine vapor in air. Fuchs (*10*) presented a theoretical treatment of mass transfer for evaporation of drops in still air.

Evaporation of droplets at finite air velocities was treated theoretically and experimentally by Froessling (*9*), but the results were based largely on the evaporation of materials of low volatility so that the problem was essentially one of mass transfer only. Froessling's data along with other literature data were reviewed by Williams (*29*) who was primarily interested in the evaporation of mustard gas, a substance of low volatility.

As far as the evaporation of drops containing dissolved and suspended solids is concerned, the available data (*32*) are meager and inconclusive, and offer no basis for the prediction and explanation of phenomena associated with the constant-rate period. For the falling-rate period only the studies of Van Krevelin (*27*) on the drying of single particles seem applicable.

Theoretical Considerations

The evaporation of a liquid drop is essentially an operation in which heat for evaporation is transferred by conduction and convection from hot gases to the drop surface from which vapor is transferred by diffusion and convection back into the gas stream. The rate of transfer per unit area of interface is a function of the temperature, humidity, and transport properties of the gas, and the diameter, temperature, and relative velocity of the drop.

Boundary layer theory predicts that the rate of transfer is a maximum on the front side of the drop facing the oncoming air stream, decreases to a minimum value near the separation point, and increases to another, but lower, maximum rate on the trailing face which experiences velocities in the reverse direction. Such a distribution of mass-transfer rates was shown by Froessling (*9*) for the sublimation of a naphthalene bead.

Figure 1 shows a temperature difference exploration around an evaporating water drop. It is evident that the rate of heat transfer will be largest on the side facing the air stream where the temperature gradient is steepest and the isotherms are close together. This temperature exploration reveals the significant fact that the thickness of the boundary layer is, in general, of the same order of magnitude as the diameter of the evaporating water drop. Thus, any theoretical development or empirical correlation should account for the variable cross-sectional area of transfer through the boundary layer.

Heat- and Mass-Transfer Equations for an Evaporating Drop. From Froessling's boundary layer equations for a blunt-nosed body of revolution (*9*) and from equations for heat and mass transfer, a set of four dimensionless partial differential equations can be developed for the evaporation of a liquid drop in an air stream. These may be written in dimensionless quantities as follows:

$$\left(\frac{1}{N_{Pr}N_{Re}}\right)\left\{\frac{1}{R^2}\frac{\partial}{\partial R}\left(R^2\frac{\partial T}{\partial R}\right)+\frac{1}{R^2 sin\theta}\frac{\partial}{\partial R}\left(\sin\theta\frac{\partial T}{\partial \theta}\right)\right\}=\frac{V_r\partial T}{\partial R}+\frac{V_\theta\partial T}{R\partial\theta}$$

(Heat balance) (1)

$$\left(\frac{\pi}{N_{Re}N_{Re}f_f}\right)\left\{\frac{1}{R^2}\frac{\partial}{\partial R}\left(R^2\frac{\partial P_A}{\partial R}\right)+\frac{1}{R^2 sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial P_A}{\partial \theta}\right)\right\}=\frac{V_r\partial P_A}{\partial R}+\frac{V_\theta\partial P_A}{R\partial\theta}$$

(Mass balance on component A) (2)

$$\frac{V_\theta\partial V_\theta}{R\partial\theta}+\frac{V_r\partial V_\theta}{\partial R}=-\frac{1}{R}\frac{\partial P}{\partial\theta}+\frac{1\partial^2 V_\theta}{N_{Re}\partial R^2} \quad (3)$$

(Force balance—modified Navier-Stokes equation)

$$\frac{1\partial}{R\partial\theta}(R\,sin\theta V_\theta)+\frac{\partial}{\partial R}(R\,sin\theta V_r)=0 \quad (4)$$

(Equation of continuity)

with boundary conditions:

(1) $T = P_A = 0$, $V_\theta = V_r = 0$, at $R = \frac{1}{2}$

(2) $T = P_A = 1.0$, at $R = \infty$; $V_\theta = v'_\theta/v_o$; $V_r = v'_r/v_o$, at $R > \delta/D_p$

where δ is the thickness of the boundary layer. Mathematically the boundary layer is defined as the region of velocities whose magnitudes are less than those for potential flow because of the retarding effect of friction at the interface.

A general solution of this formidable set of equations is not possible, and such a solution is not justified in view of the numerous assumptions which must be made regarding average physical properties across the transfer path, and in view of the existence of drop rotation, drop vibration, and unsteady-state phenomena. However, the heat- and mass-transfer numbers can be shown to take the theoretical and functional form

$$N_{Nu}=-\frac{1}{2}\int_o^\pi\left(\frac{\partial T}{\partial R}\right)_{R=\frac{1}{2}}\sin\theta d\theta = N_{Nu}(N_{Re},(N_{Re}N_{Pr})) = N_{Nu}{}'(N_{Re},(N_{Re}N_{Pr})) \quad (5)$$

$$N_{Nu'}=-\frac{1}{2}\int_o^\pi\left(\frac{\partial P_A}{\partial R}\right)_{R=\frac{1}{2}}\sin\theta d\theta = N_{Nu}{}'\left(N_{Re},\left(N_{Re}N_{Sc}\frac{f_f}{\pi}\right)\right) = N_{Nu}\left(N_{Re},\left(N_{Re}N_{Sc}\frac{f_f}{\pi}\right)\right) \quad (6)$$

The analogy shown by Equations (5) and (6) arises from the fact that Equations (1) and (2) are mathematically equivalent and subject to the same boundary conditions. Thus, N_{Nu} and N_{Nu}' should have exactly the same functional form where N_{Pr} for heat transfer is equivalent to $N_{Sc}f_f/\pi$ for mass transfer. This is an important conclusion, applicable to all heat- and mass-transfer problems where the rate of transfer is controlled by the boundary layer.

Since f_f/π is nearly unity in most applications, it is omitted as a factor on N_{Sc} in the material which follows and is implied only as a correction in broad extrapolations of recommended results.

Limiting Condition at Zero Reynolds Number. Since the physical situation in finely dispersed systems is such that the relative velocity and N_{Re} become vanishingly small, the limiting case for a drop evaporating in still air is of practical importance. For $v_\theta = v_r = 0$, Equations (1), (2), (5), and (6) give the relationship

$$N_{Nu} = N_{Nu}{}' = 2.0 \quad (7)$$

From Equation (7) it can be shown that the rate of change of surface area

of a pure liquid drop is constant during evaporation and that the total lifetime of such a drop is proportional to the square of the original drop diameter, facts reported empirically and theoretically by many investigators (*9, 10, 18, 29*).

Forced Convection. For finite velocities several solutions based on simplifying assumptions have been proposed. Johnstone and Kleinschmidt (*14*) in an absorption study postulated a hypothetical tube of gas, described by the trace of the periphery of a liquid particle in motion through a gas, whose thickness is equal to the distance heat and/or mass can be transferred in the time it takes the particle to move through one diameter. Johnstone, Pigford and Chapin (*15*) developed a solution of the Boussinesq type for heat transfer. These simplified solutions failed to give a finite value of 2.0 for $N_{Re} = 0$. To obtain the proper limiting value of $N_{Nu} = 2.0$ at $N_{Re} = 0$, Johnstone, Pigford and Chapin (*15*) developed a solution to Equations (1) and (5) on the assumption that $V_\theta = 1.0$ and $V_r = 0$ at all $R > 1/2$.

Experimental data on mass-transfer rates for spheres may be correlated by an empirical equation of the form used by Froessling (*9*):

$$N_{Nu}' = 2.0 + K_1(N_{Sc})^m(N_{Re})^n \tag{8}$$

where K_1 is a constant, $m = 1/3$ and $n = 1/2$. By analogy heat-transfer data should be correlated by a corresponding equation:

$$N_{Nu} = 2.0 + K_2(N_{Pr})^p(N_{Re})^q \tag{9}$$

where

$$K_1 = K_2,\ p = m = 1/3,$$

and

$$q = n = 1/2.$$

Equations (8) and (9) are both consistent with the theoretical requirement that $N_{Nu} = N_{Nu}' = 2$ at $N_{Re} = 0$. At high values of N_{Re}, the constant term becomes less significant, so that Equations (8) and (9) may be converted to the familiar j-factor equations of Chilton and Colburn (*4*).

Free Convection. At zero relative velocity, if heat transfer is by simple conduction and mass transfer is by simple diffusion, $N_{Nu} = N_{Nu}' = 2.0$. In the practical case, however, a density difference exists across the transfer path, and a fluid velocity caused by free convection contributes to the transfer rate. To account for this effect, it is proposed

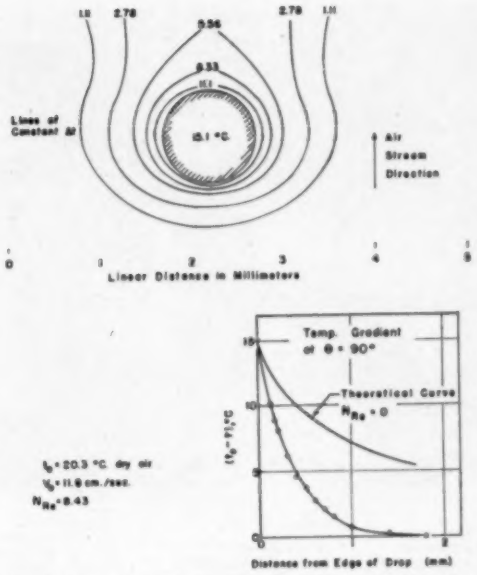


Fig. 1. Temperature exploration around an evaporating water drop.

that the velocity term in N_{Re} be taken as $|\bar{v}_\theta + \bar{v}_{f.c.}|$ where $\bar{v}_{f.c.}$ is a velocity component due to free convection parallel to gravity. If $|\bar{v}_{f.c.}|$ is taken equal to $(D_p g \beta \Delta t)^{1/2}$, Equations (8) and (9) for $v_\infty = 0$ become

$$N_{Nu}' = 2.0 + K_1(N_{Sc})^{1/3}(N_{Gr})^{1/4} \tag{10}$$

$$N_{Nu} = 2.0 + K_2(N_{Pr})^{1/3}(N_{Gr})^{1/4} \tag{11}$$

These are consistent with standard empirical correlations for free convection (*22*), at least insofar as the functional form of N_{Gr} is concerned.

Surface Conditions. In order to calculate evaporation rates, surface temperatures, t_i, and/or surface partial pressures, p_{Ai}, must be known. To estimate t_i and p_{Ai} a simultaneous graphical solution of two equations must be made. One of these equations is the temperature vapor-pressure relationship, and the other equation is a balance between the rate of heat and mass transfer. These equations may be written as follows:

$$p_{Ai} = p_{Ai}(t_i) \tag{12}$$

and

$$k\Delta t N_{Nu}(N_{Re}, N_{Pr})/D_p + \sigma\epsilon\,(T_r^4 - T_i^4) = \lambda_i D_v \rho \Delta p_A N_{Nu}'(N_{Re}, N_{Sc})/M_m D_p p_f \tag{13}$$

where Equation (13) equates the heat transferred by conduction, convection and radiation to the latent heat of evaporation. Either side of the equation may be used to represent the evaporation rate.

For simultaneous heat and mass transfer under conditions of large temperature and concentration driving forces, corrections for sensible heat carried by the vapor molecules and diffusion due to thermal gradients must be taken into account (*5*). Such effects were negligible in this study.

Effect of Dissolved and Suspended Solids. When a droplet contains dissolved materials which lower the normal vapor pressure of the liquid, p_{Ai} is not only a function of t_i but also a function of the concentration of the nonvolatile component in the surface liquid. The net result is to lower Δt and Δp_A, such that the evaporation rate becomes lower than that for pure drops of the same size. This effect would not be expected for solutions or suspensions of inert materials, and drops containing such materials can be treated as evaporating at the same rate as pure drops of the same size.

When the normal vapor pressure of the liquid is lowered by dissolved solids, it can be assumed that the drop evaporates at any average concentration as though it were saturated throughout. Hence partial pressure for saturated solutions can be used in Equation (12). This simplification is based on the fact

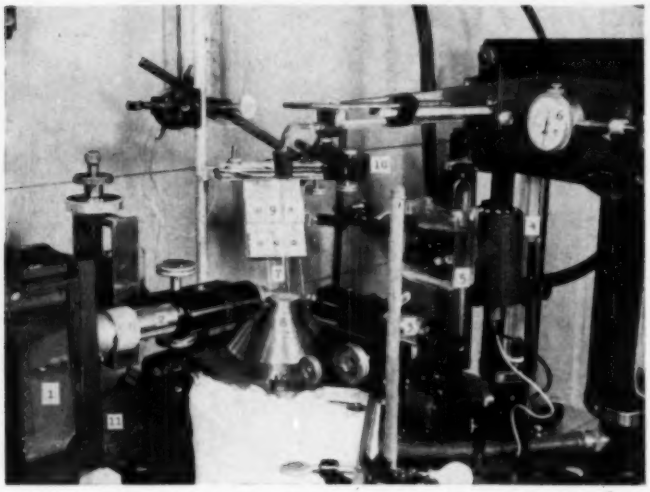


Fig. 2. Photograph of experimental equipment.

1. Micam camera.
2. Projection microscope
3. Viewing microscope.
4. Projection light.
5. Filter.
6. Microburet.
7. Suspension capillary.
8. Nozzle.
9. Thermoelement carrier.
10. Traversing mechanism.
11. Cold junction.

that diffusion coefficients in water are on the order of 10^{-5} sq.cm./sec., so small that solids will concentrate in the surface by evaporation much faster than they can diffuse toward the center of the drop.

If the heat evolved by crystallization is significant in comparison with the latent heat of evaporation, then the constant-rate period must be treated as two separate periods with a different surface temperature for each period. The first period can be treated as before. In the second period during crystallization, t_i must be calculated from an energy balance which includes the heat of crystallization. This heat contributes to evaporation and increases t_i. Although Δt is smaller, the rate of evaporation is lower since the total amount of heat being supplied for evaporation is larger and p_{Ai} has increased. From a treatment analogous to that of Williams and Schmitt (*30*), a heat balance gives

$$\lambda_i D_v \rho \Delta p_A N_{Nu}'(N_{Re}, N_{Sc})/D_p M_m p_f = k \Delta t N_{Nu}(N_{Re}, N_{Pr})/D_p + CD_v \rho \Delta p_A N_{Nu}'(N_{Re}, N_{Sc})/D_p M_m p_f \quad (14)$$

where the effect of radiation is neglected and C is the heat evolved by crystallization per unit quantity of water evaporated from a saturated solution.

Since N_{Nu} is nearly equal in value to N_{Nu}' for water vapor in air, the ratio of vapor pressure difference to temperature difference for crystallizing aqueous solutions becomes

$$\frac{\Delta p_A}{\Delta t} = -\frac{kM_m p_f}{(\lambda_i - C) D_v p} \quad (15)$$

Thus, if C is significant, the slope of the wet-bulb line, given by Equation (15), is increased; and the temperature t_i, where it crosses the curve for the vapor pressure over a saturated salt solution, is also increased.

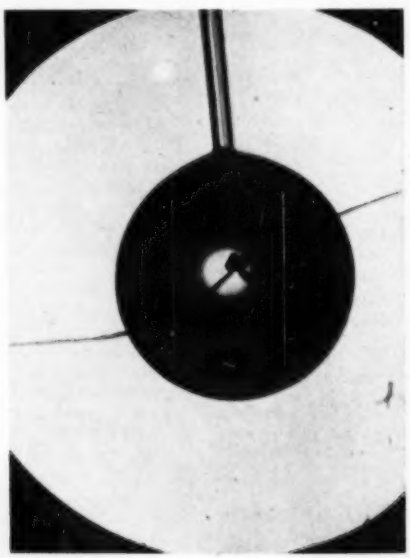


Fig. 3. Photomicrograph of an evaporating water drop, suspended from a feed capillary, with a ½ mil manganin-constantan thermoelement junction at its center. D_p = 0.0945 cm.; capillary diam. about 80 μ.

Experimental Equipment, Procedures, and Measurements

Rates of evaporation and heat transfer were obtained by a microtechnique in which drops of about one millimeter diameter were suspended from a microburet in a vertical, upward-flowing stream of air. Evaporation rates were determined by measuring the rate of feed through the buret necessary to maintain a constant-drop diameter. The temperature of the drop and the air stream were measured with small thermoelements. Evaporation rates in still air were determined in a special dryer. Suspended drops with decreasing diameters were evaporated in hot air streams and in still air, and the rate of evaporation was observed through a microscope and recorded on motion picture film.

The Air Stream and Measurement of Air Velocity. Metered dry air entered the bottom of a vertical 3¼-in. I.D., insulated tube, passed through a 200-w. electric heater, and then through a 4-in. depth of 4-mm. glass beads for distribution and an additional 4-in. depth of copper turnings for temperature stability. The tube was 40-in. long and terminated in a smoothly convergent nozzle of a shape suggested by Mache and Hebra (*19*). The nozzle opening was covered by a 140-mesh copper screen which made the velocity uniform over the opening and everywhere equal to the average volumetric velocity.

For velocities less than 300 cm./sec., point velocity mapping with a hot wire anemometer of the type used by King (*16*) showed that the screen evened the velocity distribution to the point where the volu-

metric rate through the flow meter gave an accurate measure of the central velocity. Velocity profiles taken 0.2 cm. above the nozzle persisted to some distance. The anemometer did not detect velocity fluctuations over the screen until the wire was less than 0.1 cm. from the opening. No indication of increased transfer due to turbulence created by the screen was noted in any of the tests.

Evaporation tests with air temperatures between 85° and 220° C. were made by suspending a drop on a fine filament over a hot, dry air stream and recording the history of evaporation on motion picture film. The hot air stream issued from a 25-mm. I.D. glass tube clamped to a swinging arm, and was moved under the suspended drop at the moment an evaporation test was started. The tube was filled with glass beads and covered with a 140-mesh screen, so that a uniform distribution of velocity could be assumed.

Method of Drop Suspension. Drops were suspended from a glass capillary, sealed to the delivery tube of a microburet, which had a capacity of 0.01 ml. in units of 10^{-4} ml. The capillaries were drawn so that the large end was the size of the ground glass tip of the microburet and the small end was 60 to 100μ in diameter. Since a drop would climb up the side of a plain glass capillary, they were coated with No. 9987 Dri-film to ensure that the drop hung freely from the tube.

This type of suspension system seemed to duplicate most nearly the case of a free drop. Much more than half the evaporation occurred on the side facing the air stream, and in this system the side presented to the air stream showed no protuberances. In addition, it was reasonable to believe that nearly the same type of eddying as that for a free drop occurred on the rear side, in contrast to what might be obtained if, for example, the drops were supported on horizontal wires or filaments. The suspended drop rotated at a linear velocity which appeared to be less than one per cent of the air velocity, and the rotation did not seem to be affected by the presence of the capillary. The effect of rotation was negligible in these experiments as it probably is in the evaporation of free drops falling at low Reynolds number.

Figure 2 shows the buret in place with the capillary positioned vertically over the center of the nozzle opening. The bottom of the drop cleared the screen about 0.3 cm. Evaporation rates for constant diameter drops were determined by measuring the rate of feed through the buret necessary to maintain a constant diameter.

Measurement of Drop Diameter. Figures 2 and 4 show pictures of the illumination and projection system used to observe the evaporating drop and measure its diameter. The drop image was projected and measured on the ground glass screen of a microscope camera. Figure 3 is a photograph of a drop as it appeared on the camera screen. Another microscope with long focal length objective and high-power eyepiece was used to observe the drop in reflected light and to aid in centering the thermoelement inside the drop. With room-temperature air, the diameter of a drop was easily kept within a tolerance of ±0.03 cm. on the screen.

In tests with hot air and changing drop diameter, motion pictures were taken at a magnification of approximately 7 times on the film, and at a rate of 24 frames/sec. Drop diameters were measured frame by frame on a microfilm viewer. In this case, diameter and time measurements were a measure of the evaporation rate.

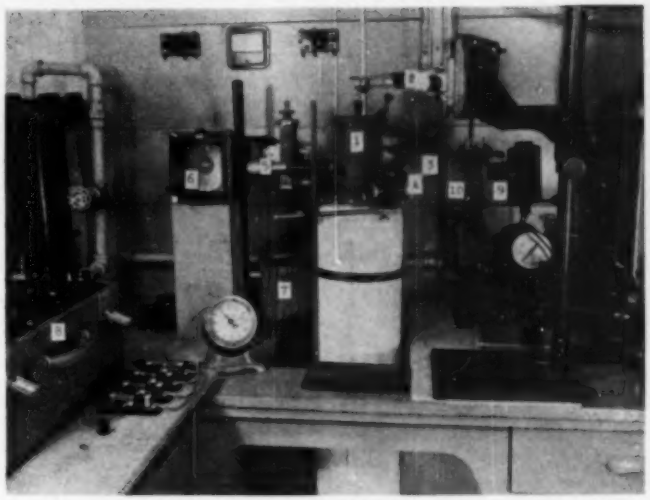


Fig. 4. Equipment for evaporation of drops in still air.

1. Special dryer.
2. Microburet.
3. Thermoelement carrier.
4. Observation microscope.
5. Projection microscope.
6. Micam camera screen.
7. Cold junction.
8. Potentiometer.
9. Projection light.
10. Filter.

Measurement of Air Temperature and Drop Temperature. Air temperatures and drop temperatures were measured with calibrated thermoelements of 3 mil, 2 mil, 1 mil, and ½ mil manganin-constantan wire. The thermocouples were held between needles mounted in a wood block which was carried by a traversing mechanism that made it possible to move the junction in a horizontal plane above the nozzle (see Figure 2). Four couples were usually in operation at one time, 2 mil, 1 mil, and ½ mil wires being employed in series for extrapolation to a true temperature. It is believed that temperature readings to the nearest 0.1° C. were obtained.

During any one run (from 5 to 20 min.) the temperature of the air stream, measured by the fine thermoelements, never varied more than 0.2° C. and in most cases less than 0.1° C. The air temperature was

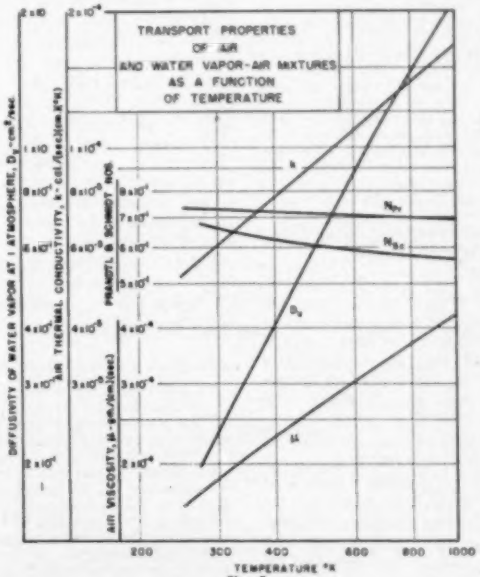


Fig. 5.

taken as the average temperature for the complete test run.

The temperature of the drop was measured by embedding a thermoelement junction inside the drop (see Figure 3). The junction had to be perfectly clean to accomplish this feat.

The thermocouple and its leads, the capillary, and the addition of sensible heat in the feed liquid, complicated the heat balance. An attempt was made to determine the magnitude of these various factors by taking temperature measurements under special conditions, for example, while feeding, while not feeding, with the capillary in place, and with the drop hanging from the thermoelement junctions. During evaporation tests, the thermoelement was removed so as not to disturb the flow pattern and provide an additional path for heat conduction. Consequently, the drop temperature for a test run was determined before the test by taking drop temperatures with 2-mil, 1-mil, and ½-mil thermoelements centered in a constant diameter drop being fed and evaporated under similar conditions as the test run.

For tests at 85° to 220° C., the air temperature was measured with a high velocity copper-constantan thermocouple at the center line, 0.3 cm. above the opening of the swinging air jet, and the drop temperature was approximated in separate tests by rapidly taking temperatures of drops suspended on thermoelements after the hot air stream was swung under the drop.

In every case measured drop temperatures were, for practical purposes, the same as wet bulb temperatures estimated from a standard psycrometric chart. The error in Δt's approximated from a psycrometric chart was never more than 4% for forced convection.

Measurement of Evaporation from Drops in Still Air

Figure 4 shows a special dryer for the study of evaporation rates in still air. The bottom and upper portions of the drying unit with the exception of observation windows and probe holes were filled with silica gel, and the entrance holes for the thermoelement apparatus and buret tip were sealed with plasticine.

The drop evaporated with changing diameter as it hung on a thermoelement or with constant diameter as it hung on a capillary. The temperature difference, Δt, was determined by an opposed-type thermoelement with junctions on a horizontal line one centimeter apart; the drop was suspended on one of the junctions.

Transport Properties of Air and Water Vapor

A critical review of the transport properties of air and water vapor was made to ensure reliable correlations of experimental data. The values used in calculations are given in graphical form by Figure 5, and the correlations presented later are dependent on these values.

Specific heats at constant pressure were taken from statistical mechanical calculations (*6*). Viscosity values were obtained by calculations based on the Lennard-Jones intermolecular potential (*3, 12*) and are in close agreement with careful experimental measurements (*2, 13, 28*). Values of thermal conductivity are from the experimental data of Taylor and Johnson (*26*), the values for temperatures above 380° K. being obtained by extrapolation.

Recommended values of the diffusion coefficient of water vapor in air were calculated as a first approximation by R. B. Bird (*12*) from experimental measurements of the dipole moment and second virial coefficient of steam and the polarizability of air. The calculated values agree excellently with the original data of Winklemann (*31*) both in magnitude and temperature dependency but are approximately 10 per cent lower than that indicated by the S.T.P. value given by the International Critical Tables. A wide scattering of experimental values of diffusivity for air-water vapor mixtures are available, the latest work being that of Schirmer (*25*). However, every experimental method has involved a liquid-gas interface and a diffusion path of indefinite length. Because of such experimental difficulties (all the expected errors tend to give high values for D_v), because of the experimental value of N_{Nu}' at $N_{Re} = 0$ obtained in this study, and because of the greater consistency in calculated and experimental wet-bulb temperatures in this and related mass-transfer operations, the theoretical values of D_v listed here are considered to be the most accurate. The only other phenomenon which could explain the observed facts and cause a high apparent D_v would be the modification of the widely accepted assumption that the partial pressure of vapor at a liquid surface of temperature t_i is the equilibrium vapor pressure at temperature t_i. This implies an accommodation coefficient of 1.0, which may or may not be true for water surfaces (*9*).

Calculation Procedures

To determine the experimental value of N_{Nu} or $N_{Nu'}$ a major assumption made was that the surface temperature of the drop, t_i, was everywhere the measured value, and that the partial pressure of water vapor at the surface p_{Ai} was everywhere equal to the saturation partial pressure of water vapor at t_i. Since the thermal conductivity of water at 20° C. is 1.43×10^{-4} cal./(sec.)(cm.)(° C.) or 25 times as great as that of air, the temperature of the drop was assumed uniform throughout and equal to the experimentally measured temperature. Actual measurements showed that the position of the thermoelement junction within the drop had no apparent effect on the indicated temperature.

The Nusselt group for mass transfer was determined by inserting the experimentally determined values and transport properties in the following equation:

$$N_{Nu'} = \frac{r_{Ait} D_p M_m \bar{p}_f}{\Delta p_A D_v \rho} \qquad (16)$$

Since water vapor at most represented but one per cent of the gas mixture, the physical properties of the transfer path were taken as those of dry air at the arithmetic average temperature. No correction was made for the cross-sectional area of the capillary since it represented less than 0.2 per cent of the drop surface.

The Nusselt number for heat transfer was more difficult to obtain since sensible heat added in the feed, transferred by conduction along the capillary, and brought in by radiation had to be considered. Since the heat transferred by all methods must equal the latent heat of evaporation, a heat balance gives

$$\begin{aligned} q_{Ai} = \lambda_i r_{Ait} &= h_c \Delta t && \text{(convection and conduction)} \\ &+ r_{Ait} C_i \Delta t && \text{(sensible heat)} \\ &+ \sigma\epsilon (T_s^4 - T_i^4) && \text{(radiation)} \\ &+ r_{Ait} \lambda_i \left[\frac{\Delta(\Delta p_A)}{\Delta p_A}\right]_c && \text{(conduction along capillary)} \end{aligned} \qquad (17)$$

Equation (17) in terms of the Nusselt number becomes

$$N_{Nu} = \frac{h_c D_p}{k} = \frac{r_{Ait} \lambda_i D_p}{\Delta t\, k} \left\{ 1 - \frac{\Delta t C}{\lambda_i} - \frac{\sigma\epsilon 4 T^3 \Delta t}{\lambda_i r_{Ait}} - \left[\frac{\Delta(\Delta p_A)}{\Delta p_A}\right]_c \right\} \qquad (18)$$

where $(\Delta(\Delta p_A)/\Delta p_A)_c$ is the percentage change in Δp_A caused by the presence of the capillary. This fractional change in partial pressure difference was determined by drop temperature measurements with and without the capillary in place. Equation (18) shows the true value of N_{Nu} as an apparent N_{Nu} corrected by a series of terms. For a typical test (No. 80) the values of the correction terms were as follows:

$$\begin{aligned} N_{Nu} &= 5.83(1 - 0.028 - 0.006 - 0.011) \\ &= 5.57 \end{aligned}$$

Since the corrections for radiation and capillary effects were small, and since the correction for sensible heat was excessive (about half of it was actually realized), only the sensible heat correction was made for the points on the correlation curve, the errors in this procedure tending to cancel one another.

Although evaporation and heat-transfer rates in still air were obtained at constant diameter, it was considered more accurate to support the drop on a fine thermoelement and determine evaporation rates from the change in drop diameter with time. From such measurements the Nusselt groups can be determined from the relations

$$N_{Nu} = -\tfrac{1}{4} \frac{\lambda_i \rho_l}{\Delta t k} (dD_p^2/d\tau) \qquad (19)$$

$$N_{Nu'} = -\tfrac{1}{4} \frac{\rho_l M_m \bar{p}_f}{\Delta p_A D_v \rho_M} (dD_p^2/d\tau) \qquad (20)$$

Equations (19) and (20) can be used also in the analysis of diameter vs. time data for drops evaporating at finite air velocities. In such an application the derivative of D_p^2 with respect to time varies with the instantaneous drop size.

Part II, to be run in an early issue, will contain Notation, Literature Cited, remaining figures and all tables.

THERMAL CONDUCTIVITY OF GRANULAR SOLIDS THROUGH WHICH GASES ARE FLOWING

DONALD F. MOLINO and JOEL O. HOUGEN

Rensselaer Polytechnic Institute, Troy, New York

THIS work is an extension of that reported by Hougen and Piret (*1*) in which a generalized equation for the effective thermal conductivity of certain granular solids through which gases are flowing was presented. In the former investigation the gas (air) was cooled during downward flow through the cylindrical bed of granular material. It was the object of this work to determine any differences which might arise if the gas were heated instead of being cooled.

The equipment and methods of evaluating the thermal conductivity factor used in this work are identical to that used in the previous study (*1*). Briefly the experimental technique consisted of passing air under temperature and flow control downward through a bed of celite pellets supported in a relatively short cylindrical brass container. The container was surrounded by an annular space through which cooling or heating medium could be introduced. For the heating experiments steam at about 35 lbs./sq.in. gage was used. In both instances the surface temperature of the container was assumed to be that of the heat-exchange fluid. A diagram of the apparatus used during the work with heating is shown in Figure 1.

Upon the attainment of steady-state conditions the average temperature of the mixed influent and effluent air stream was measured as well as its humidity.

With the following assumptions the situation which prevails within the bed may be considered analogous to that existing in an infinite cylinder being heated (or cooled) through its convex surfaces:

1. Resistance to heat transfer at and through the container walls is negligible.
2. Radiant heat transfer is inconsequential.
3. Direction of net heat transfer is radial only.
4. Velocity distribution is uniform over the cross section of the container.

NOTE: Table 3 with complete data and calculations is on file (Document 3496) with American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Material obtainable by remitting $1.00 for microfilm and $1.50 for photoprints.

As was shown in the previous paper under these circumstances the integrated conduction equations applicable to the unsteady-state heating or cooling of infinite cylinders may be used:

$$\frac{t_o - t_s}{t_o - t_g} = 4 \sum_{i=1}^{\infty} \frac{1}{a_i^2} e^{-a_i^2 \left(\frac{k_e F_c Z}{C_{pm} G a^2} \right)} \tag{1}$$

and thus:

$$\frac{t_o - t_s}{t_o - t_g} = f\left(\frac{k_e F_c Z}{C_{pm} G a^2} \right) \tag{2}$$

The functional relation between the temperature ratio and the dimensionless group, $k_e F_c Z / C_{pm} G a^2$, (reciprocal modified Graetz number) is given by Equation (1). The temperature ratio is found from experimental measurements and all terms in the right side of Equation (1) are known except k_e, which may then be found by calculation.

The dimensions and pertinent properties of the celite pellets used in this work are given in Table 1, while the bed dimensions are shown in Table 2. A summary of data and calculations is given in Table 3.

TABLE 2.—BED DIMENSIONS

Diam., In.	Depth, In.	Ratio Diam./Depth
1.27	6.48	0.314
3.75	12.00	0.312
3.75	6.46	0.580

In view of the gratifying results found previously (*1*) when the group, $(k_e/k_g)F_c$, was plotted vs. the Reynolds group, $\sqrt{a_p} G/\mu_m$, this procedure was used in this work. This plot is shown in Figure 2. A straight line of slope about 0.43 and intercept (where $R_p = 1$) of 1.23 appears to fit the data fairly well except for the data marked with the Δt notation. The result therefore is the empirical relation

$$\frac{k_e}{k_g} = \frac{1.23}{F_c} \left(\frac{\sqrt{a_p} G}{\mu_m} \right)^{0.43} \tag{3}$$

TABLE 1.—DIMENSIONS AND PROPERTIES OF CELITE PELLETS

Sizes	Diam., Ft.	Length, Ft.	Void Fraction	Surface Area, a_p, Sq.Ft.
1/6	.0120	.0108	0.388	0.000635
5/32	.0148	.0148	0.421	0.001033
1/4	.0224	.0211	0.420	0.002253
5/16	.0321	.0403	0.432	0.006400

Porosity, 60%; mercury density, 0.9; thermal conductivity of solid material, 0.2 B.t.u./(hr.)/(sq.ft.)(° F./ft.) at 1000° F. (approx.)

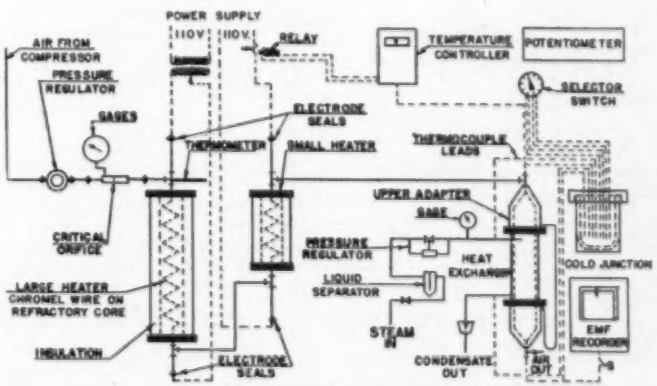


Fig. 1. Diagram of apparatus.

TABLE 3.—SUMMARY OF DATA AND CALCULATIONS

Series M

Run No.	G	t_a	t_e	t_s	$f(E) = 1/\theta s'$	k_s	R_p	$\frac{k_s(Fe)}{k_g}$
				Bed 1.37 in. in Diam. and 6.43 in. in Depth				
				½-in. Celite Cylinders				
2	4209.8	108.6	218.0	286.4	.105	1.68	2149	37.9
3	1926.3	117.6	234.7	290.0	.134	.98	966	21.8
4	2666.1	130.9	230.9	290.1	.120	1.21	1338	27.0
				5/32-in. Celite Cylinders				
14	2636.8	108.2	229.4	288.8	.129	1.21	1709	28.8
15	1895.0	108.3	234.1	288.8	.144	.97	1221	23.1
16	4251.4	107.6	221.4	287.5	.113	1.69	2768	40.7
				¼-in. Celite Cylinders				
18	4236.7	109.5	220.2	287.6	.107	1.58	4089	38.8
20	2627.1	112.4	228.3	287.4	.127	1.17	2518	28.5
22	1889.1	111.8	233.4	287.2	.144	0.96	1800	23.2
				Bed 3.75 in. in Diam. and 6.46 in. in Depth				
				¼-in. Celite Cylinders				
30	352.7	112.2	196.9	287.7	.059	.59	181.8	13.5
31	253.7	118.0	209.1	287.6	.073	.52	129.3	11.8
32	570.7	103.6	179.7	287.3	.042	.68	306.3	15.8
				5/32-in. Celite Cylinders				
34	408.0	114.0	194.1	287.3	.053	.57	289.5	13.9
35	570.0	113.0	184.8	287.9	.041	.62	379.0	15.2
36	253.4	114.0	205.4	286.6	.078	.49	165.7	11.9
				¼-in. Celite Cylinders				
39	253.7	112.2	209.6	286.9	.082	.54	245.4	13.3
42	408.9	109.7	196.7	287.6	.061	.65	402.2	16.2
43	570.0	107.2	185.8	287.0	.047	.70	566.6	17.6
				⅜-in. Celite Cylinders				
45	569.4	105.0	187.2	287.2	.051	.74	947.4	19.0
46	254.6	110.0	213.9	287.4	.093	.60	413.4	15.1
47	353.1	108.3	204.1	289.2	.073	.65	580.2	16.6
				Bed 3.75 in. in Diam. and 12.00 in. in Depth				
				½-in. Celite Cylinders				
65	572.0	114.6	207.8	288.4	.074	.64	291.9	14.5
66	256.4	114.7	223.8	284.2	.117	.45	129.5	10.2
67	355.1	114.9	215.8	284.5	.095	.51	180.7	11.6
				5/32-in. Celite Cylinders				
59	255.3	114.2	226.3	286.4	.121	.47	164.8	11.2
61	485.5	113.8	210.1	286.4	.082	.57	316.9	13.7
63	568.1	114.0	207.6	286.2	.076	.62	371.3	14.9
				¼-in. Celite Cylinders				
49	255.0	114.6	230.5	287.5	.131	.47	242.4	11.3
51	490.1	115.0	218.2	286.4	.093	.59	471.3	16.9
53	571.4	114.8	209.7	287.5	.079	.67	551.6	16.5
				⅜-in. Celite Cylinders				
55	570.0	114.6	221.3	289.7	.100	.78	919.4	19.5
56	255.6	114.0	239.1	285.3	.167	.58	408.3	14.4
57	354.4	114.0	230.7	284.5	.138	.67	568.4	16.7

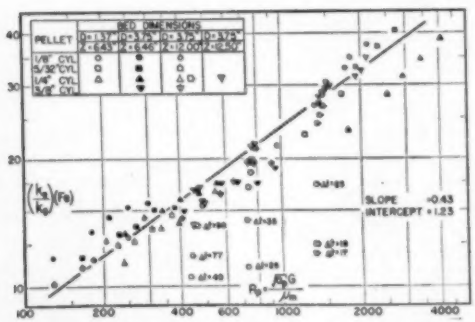


Fig. 2. Plot of $\left(\frac{K_s}{K_g}\right)(Fe)$ vs. Reynolds number for various pellet sizes in beds of different dimensions; heating in downward flow.

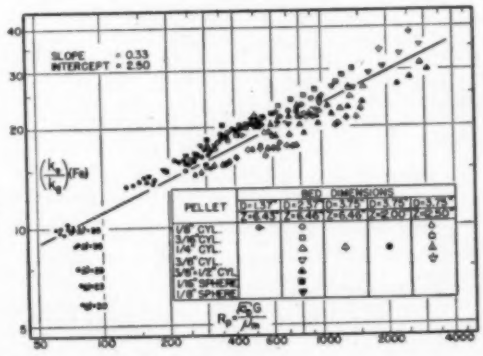


Fig. 3. Plot of $\left(\frac{K_s}{K_g}\right)(Fe)$ vs. Reynolds number for various pellet sizes in beds of different dimensions; cooling in downward flow.

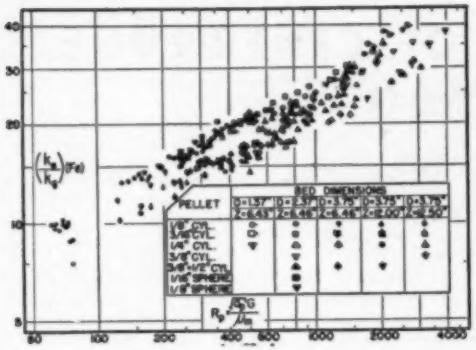


Fig. 4. Plot of $\left(\frac{K_e}{K_g}\right)(Fe)$ vs. Reynolds number for various pellet sizes in beds of different dimensions, heating and cooling in downward flow.

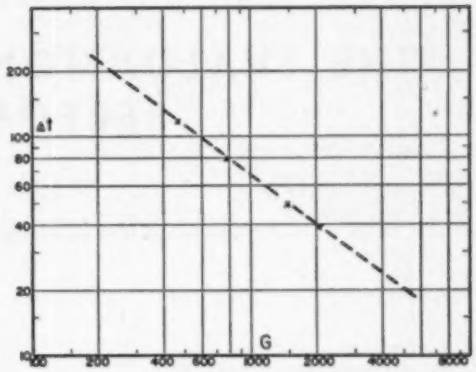


Fig. 5. Approximate values of average radial temperature difference below which significant deviations from the correlation occurs as a function of mass velocity. Heating of ¼ in. celite cylinders in a bed 3.75 in. in diam. and 12.5 in. deep.

Data previously obtained for the case where the air was cooled are shown in Figure 3, plotted in a similar manner. The best fit is given by the relation

$$\frac{k_e}{k_g} = \frac{2.50}{Fe}\left(\frac{\sqrt{a_p}G}{\mu_m}\right)^{0.33} \quad (4)$$

Although independent plots seem to indicate some differences between heating and cooling, all data were combined in a single plot and are presented in Figure 4. From a further study of Figure 4 it was found, although no line was actually established, that the following single equation seems to correlate fairly accurately both heating and cooling data:

$$\frac{k_e}{k_g} = \frac{1.23}{Fe}\left(\frac{\sqrt{a_p}G}{\mu_m}\right)^{0.43} \quad (5)$$

As was previously observed during the cooling experiments, as the absolute value of the average radial temperature gradient is reduced, a point is reached where the effective conductivity, as evaluated by the methods used herein, rapidly diminishes. Typical results are indicated on each plot and marked with the corresponding value of $\Delta t = /t_m - t_a/$. For a given bed dimension and pellet size there appears to be a critical value of Δt below which k_e values fall off rapidly, this value being dependent upon the mass velocity of the gas. In Table 4 the critical Δt values are listed vs. mass velocity for the case of ¼-in. celite cylinders in a bed 3.75 in. in diam. and 12.5 in. deep. These data are plotted in Fig. 5. The same phenomenon occurs during cooling although somewhat lower radial temperature gradients may be tolerated before the correlation fails.

TABLE 4.—VALUES OF Δt BELOW WHICH THE CORRELATION PREDICTS HIGH VALUES FOR A GIVEN MASS VELOCITY

¼-in. Celite Cylinders in a Bed 3.75 in. in Diam. and 12.5 in. Deep. Heating in Downward Flow

$\Delta t = t_a - t_m$, °F.	Avg. Radial Temp. Gradient $\Delta t/a$, °F./in.	Mass Velocity G lb./(hr.)(sq.ft.)
110	59	500
80	43	800
50	27	1500
40	21	2000

No comparison of the results herein presented with those of others will be made; indeed, it is difficult to do so, except in a qualitative way, because of differences in experimental techniques, methods of evaluating conductivity and differences in the nature of the solid material. Verschoor and Schuit (*2*) used essentially the same methods as used here but used a variety of materials none of which evidently had as low a conductivity as celite. It is therefore difficult to make a direct comparison with their results. The correlation presented by these workers includes a term to account for the static conductivity of the bed and in addition includes the term (SD_c), which is dependent upon a ratio the size of the pellets with respect to the bed diameter.

$$\frac{k_e}{k_g} = \frac{k_e^\circ}{k_g} + 0.10(SD_c)^{0.5}\left(\frac{\rho u}{\mu S}\right)^{0.60} \quad (6)$$

The authors failed to observe a significant dependency upon the ratio of bed to pellet dimension; as a matter of fact it was demonstrated in the previous paper (*1*) that bed dimensions have no influence on the average conductivity values, as determined by the methods used herein, unless the ratio of bed to pellet diameter is less than approximately six. The need for the term, k_e°/k_g, to account for static conditions was not observed in this study.

Notation

a = radius of bed, ft.
a_p = average surface area of pellet, sq.ft.
C_{pm} = mean specific heat, B.t.u./(lb.)(° F.)
D_t = bed diameter, ft.
Fe = superficial void fraction in bed, dimensionless
G = mass velocity of fluid based on empty tube, lb./(hr.)(sq.ft.)
k_e = effective thermal conductivity of packed bed with flowing fluid, B.t.u./(hr.)(sq. ft.)(° F./ft.)
k_e° = effective thermal conductivity of packed bed with stagnant fluid
k_g = thermal conductivity of fluid
R_g = Reynolds number
S = particular surface area per unit volume of packed space
t_a = average temperature of effluent gas, ° F.
t_m = average temperature of gas within the bed, ° F. $t_m = (t_0 + t_a)/2$
t_0 = average temperature of inlet gas, ° F.
t_s = average temperature of container surface, ° F.
u = average linear velocity of gas
Z = bed depth, ft.
α_i = ith root of Bessel function of zeroth order
Δt = absolute value of average radial temperature gradient, °F. $\Delta t = /t_m - t_s/$
μ_m = average viscosity of fluid in bed, lb./(ft.)(hr.)
ρ = gas density

Literature Cited

1. Hougen, J. O., and Piret, E. L., *Chem. Eng. Progress*, **47**, 295 (1951).
2. Verschoor, H., and Schuit, G. C. A., *App. Sci. Res.*, **A2**, No. 2, 97 (1950).

THE EVALUATION OF CENTRIFUGE PERFORMANCE

CHARLES M. AMBLER

The Sharples Corporation, Philadelphia, Pennsylvania

CENTRIFUGES are used commercially to:

1. Separate immiscible liquids
2. Remove and recover solids from dispersion in liquids
3. Remove excess liquid from solids
4. Any combination of the first three

Two basically different types of centrifuges are employed to perform these functions. In the first, which may be described as a "settling machine," the liquid, or one of the liquid phases, is continuous and the dispersed particles of solids or of the other liquid phase are caused to migrate through it by the acceleration of centrifugal force. The critical mathematical relationship governing the velocity of migration of the dispersed phase was developed by Stokes as the law that bears his name and will become a part of this discussion.

The second basic type of centrifuge may be described as a "centrifugal filter." In it the solid phase is supported on a permeable surface, such as a screen, through which the liquid phase is free to pass under the acceleration of centrifugal force. Mathematical relationships for this type of centrifuge have not been studied to the same critical extent as for the type of centrifuge in which the liquid phase is continuous, and performance evaluation for the centrifugal-filter-type of centrifuge is almost entirely empirical.

Settling-Machine-Type of Centrifuge. For a continuous centrifuge of the settling-machine-type to do useful work, its field of force must cause the particles of the dispersed phase to migrate with a velocity, v_s, in a direction other than parallel to that of the continuous phase. The effective force operating on a particle in a centrifugal field is

$$F = (m - m^1)\omega^2 r \qquad (1)$$

where m equals the mass of the dispersed particle and m^1 the mass of the equivalent volume of continous phase that it displaces. If it is assumed that the particle is a sphere of diameter D, then the equation takes the form

$$F = \pi \Delta\rho D^3 \omega^2 r \qquad (2)$$

in which $\Delta\rho = \rho - \rho^1$, the difference in density between that of the continuous, ρ^1, and of the dispersed, ρ, phases. Since the force is directly proportional to this difference in density, it becomes obvious that such a difference must exist for centrifugal separation to occur, regardless of the size of the dispersed phase particles.

The movement of the dispersed phase particle is hindered by the resistance of the continuous phase to motion through it. For small particles moving at moderate velocities (below the turbulent range) this resisting force is proportional to the velocity of the moving particle, and for the particular case of a spherical particle is defined by Stokes' law as

$$F^1 = 3\pi\eta D v \qquad (3)$$

in which η is the absolute viscosity of the continuous phase. At equilibrium

$$v_s = \frac{\Delta\rho D^2 \omega^2 r}{18\eta} \qquad (4)$$

Since the capacity of a centrifuge is usually limited by its ability to handle the smallest particles in a given system, this formula becomes of major importance in the analysis of centrifuge performance.

When the particle is not spherical, a value for the diameter of the equivalent sphere must be used. For small particles, when particle size can also be calculated from diffusion data as well as from sedimentation velocity, it is possible to arrive at a shape factor for the particle, as illustrated in the work of T. Svedberg and others (*1*).

Stokes' law ceases to be accurate when either the sedimentation velocity or the particle diameter becomes so large that the Reynolds' number, $Dv\rho/\eta$, exceeds the order of unity. This factor is of limited interest in centrifugal work because attention is usually directed to the smaller particles that settle slowly.

In a gravitational field, the sedimentation velocity of a particle is

$$v_g = \frac{\rho D^2 g}{18\eta} \qquad (5)$$

in which g is the gravitational constant. It will be noted that this differs from the velocity of sedimentation in a centrifugal field only by the substitution of g for $\omega^2 r$.

The centrifugal field differs only from the gravitational field in that it may be thousands of times greater, and that it varies in proportion to the distance from the center of rotation, r, so that the sedimentation velocity of a particle increases as it moves outward from the axis of rotation, while in the gravitational field its equilibrium velocity is independent of its position.

If the simplest form of centrifuge is considered, a rotating cylinder with end caps, and turbulence is neglected, then v_s is the velocity with which the particle approaches the bowl wall. If one considers the liquid to lie in such a bowl in a thin layer of thickness s, and to be fed in continuously at one end and discharged at the other, then the time t during which the liquid is in the bowl is V/Q, where V is the volume of liquid in the bowl at a given time, and Q is the rate of flow of liquid through the bowl. Since it has been assumed that s is small, the velocity of sedimentation of a particle will be approximately uniform and the distance settled by the particle will be

$$x = v_s t = \frac{\Delta\rho D^2 \omega^2 r}{18\eta} \cdot \frac{V}{Q} \qquad (6)$$

If x is greater than the initial distance of the particle from the wall of such a bowl, it will be removed from the liquid phase; otherwise it will remain in suspension and be discharged with the effluent liquor. In an ideal system, when $x = s/2$, half the particles of diameter D will be removed from suspension and half will not. This condition will be considered as the "cut-off point" and the flow, Q, at cut-off will be

$$Q = \frac{\Delta\rho D^2}{9\eta} \cdot \frac{V\omega^2 r}{s} \qquad (7)$$

from which the critical diameter D may be calculated.

$$D = \sqrt{9\eta Q \cdot \frac{s}{V\omega^2 r}} \qquad (8)$$

Particles greater in size than D will be largely removed and those smaller in size will tend to remain in suspension.

For more complex centrifuges than the simple tube with a thin liquid layer, the radius, r, and the settling distance, s, must be replaced by the corresponding effective values, re and se, for these dimensions.

If in the tubular bowl the liquid layer is not relatively thin, but extends from r_1 to r_2 then it can be shown that

$$\frac{re}{se} = \frac{1}{ln\left(\frac{2r_2^2}{r_2^2 r_1^2}\right)} \simeq \frac{3/2r_2^2 + 1/2r_1^2}{r_2^2 - r_1^2} \qquad (9)$$

Equation (7) may be rewritten

$$Q = 2v_g\Sigma \qquad (10)$$

in which

$$v_g = \frac{\Delta\rho D^2 g}{18\eta}$$

and

$$\Sigma = \frac{V\omega^2 r_e}{g s_e}$$

It will be seen that the elements concerned with the liquid system are all in the first group, while the second group concerns itself with the elements relating to the centrifuge. The quantity Σ can be demonstrated to be of the area of a simple gravity settling tank of equivalent sedimentation characteristics to that of the centrifuge.

For tubular bowls the approximation

$$\Sigma = \frac{\pi_2 \pi_1 \omega^2}{g} 3/4r_2^2 + 1/4r_1^2 \qquad (11)$$

where l is the length of the liquid column, applies.

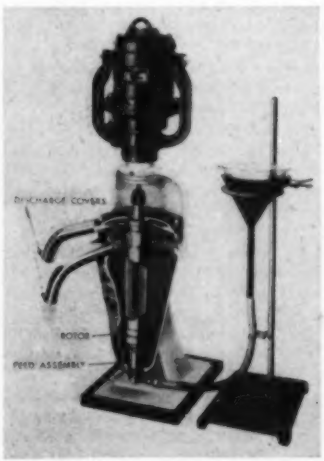


Fig. 1.

For disc-type centrifuge bowls it can be shown that

$$\Sigma = \frac{2n\pi(r_2^3 - r_1^3)\omega^2}{3g \tan\theta} \qquad (12)$$

where n is the number of spaces between the discs in the stack, r_1 and r_2 are the inner and outer radii respectively of the disc stack, and θ is the conical half angle.

It will be seen from the discussion thus far that centrifuges are operable on disperse or discontinuous systems and that to estimate the performance of centrifuges of the settling-machine-type, accurate size measurements of the dispersed particles in terms of their equivalent diameter are required. Where such measurements are possible accurate estimates of centrifuge performance under certain conditions that will be discussed later can be made. However, in the usual heterogeneous systems encountered in industry such measurements are difficult, if not impossible, to make.

According to Equation (10) the performance of any two centrifuges treating the same system will be the same if the quantity Q/Σ is held constant. Accordingly, the throughput Q_1 of centrifuge No. 1 at which its performance should equal that of centrifuge No. 2 at the observed throughput Q_2 is

$$Q_1 = \frac{Q_2\Sigma_1}{\Sigma_2} \qquad (13)$$

This relationship forms a basis for estimating commercial centrifuge performance from laboratory and pilot plant scale tests.

In theory, once a given type of commercial centrifuge has been calibrated against the laboratory size centrifuge that it is proposed to use as a standard, all tests can be made on a single standard laboratory machine. In practice, this has been found to be not the case, and it is usual to minimize to the greatest possible extent the effect of such variables as centrifugal force and bowl shape and proportion. For even reasonably accurate estimation of commercial performance a laboratory centrifuge of a type similar to the commercial centrifuge and operated at a speed to give a comparable centrifugal force is used and even then the mathematical relationship between them has to be modified by an experience factor.

When performance estimates are required on centrifuges that continuously or automatically discharge the sedimented solids, another variable, the condition of the solids under centrifugal force, is introduced. As in all chemical engineering work, experience plays an important part in indicating when the results of small-scale tests become of doubtful value and when full-scale tests must be resorted to.

TABLE 1.

	Laboratory Super-Centrifuge	No. 16 Super-Centrifuge
l	7-¾ in.	28-⅝ in.
r_2	⅝ in.	2-1/16 in.
r_2-r_1	19/32 in.	1-3/16 in.
rev./min.	23,000	15,000
V	280 cc.	5170 cc.
$\Sigma(11)$	2,460,000 sq.cm.	25,200,000 sq.cm.

The Sharples laboratory Super-Centrifuge (Fig. 1) has a tubular bowl 7-¾ in. long and 1-¾ in. in diam. Its commercial counterpart, the No. 16 Super-Centrifuge (Fig. 2) has a bowl 29 in. long and 4 in. in diam. Its normal rotational speed is 15,000 rev./min. at which it develops a centrifugal force of 13,200 times that of gravity at its extreme inside diameter. The laboratory Super-Centrifuge develops this same force at 22,700 rev./min., and this speed is normally used in tests when it is desired to estimate the performance of the larger machine on a small-scale test. The Σ value for the laboratory Super-Centrifuge when operated at 23,000 rev./min. is 280 sq.m. by Equation (9) and 286 sq.m. by approximation Equation (12), while that of the No. 16 Super-Centrifuge is 2,470 and 2,520 sq.m. by the same formulae. The constants for these two machines are summarized in Table 1.

Experimental tests with low concentrations of thoroughly dispersed satin clay in water at relatively low values for Q support these mathematical analyses.

At values for Q, in what may be considered as a commercially practical range, of 100 gal./hr. to 400 gal./min. for the No. 16 Super-Centrifuge, which should correspond to 11.4 gal./hr. to 44.6 gal./hr. for the laboratory Super-Centrifuge, experience has indicated

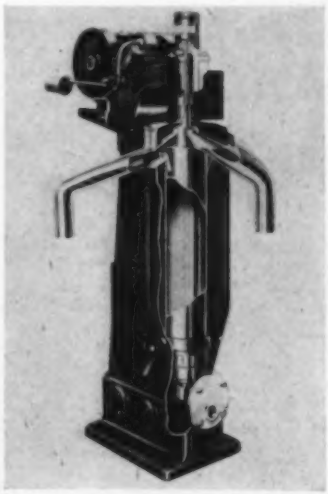


Fig. 2.

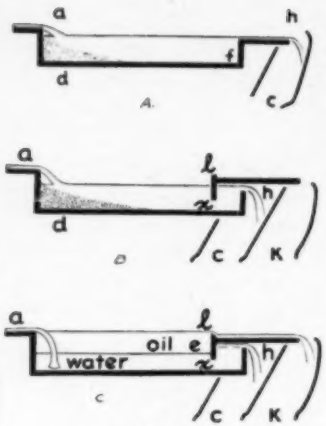


Fig. 3.

that a Σ No. 16/Σ laboratory ratio of the order of 20 to 1 more nearly applies. At higher values of Q, the observed ratio becomes even greater and increasingly more erratic on various materials while at lower values of Q the observed ratio approaches the calculated.

For practical consideration, it may be stated that within the capacity limits of 300 to 1200 ml./min., the Sharples laboratory Super-Centrifuge when operated at 23,000 rev./min. will duplicate the performance of the No. 16 Super-Centrifuge operated at 15,000 in more than 90% of the tests run when the same numerical value for Q is used, expressed as milliliters per 20 seconds for the former and gallons per hour for the latter. This performance estimate applies not only to clarification, i.e., the removal of dispersed solids from liquid, but also for the separation of two immiscible liquids after the optimum position for their interface has been established.

A number of reasons may be advanced to show why this discrepancy between calculated and practical results occurs. The significant point is that it does occur and must be recognized in evaluating the performance of two centrifuges even though they are as closely related mechanically as these two.

When the problem involves the separation of immiscible liquids, the most critical point is the control of the interfacial surface so that in any given centrifuge of fixed dimensions the optimum amounts of the heavy- and light-liquid phases are retained within the bowl. The gravitational analogue of this type of centrifuge, a simple settling tank, will serve to illustrate this point.

Figure 3-a is a simple gravity settling trough suitable for removing heavy solids from a liquid. By modifying this trough with a baffle as shown in Figure 3-b, it can be used to separate a light phase. Use of such a trough for the continuous separation of two liquid phases is shown in Figure 3-c. The position of the interfacial surface, e, can be controlled by changing either dimension l or dimension h. In practice, dimension h is usually the variable, (1) because it does not affect the total volume of liquid v, and (2) the adjustment is much more sensitive.

In any given system of this type it is usually found that one component is more difficult to bring to the required state of purity than the other. In such cases, maximum effective capacity is obtained by providing greater detention volume for that component by adjusting the position of the interfacial surface. The method for accomplishing this in the Super-Centrifuge is shown in Figure 4. With all dimensions measured from the axis of rotation it can be shown that—

$$E = \frac{\text{density heavy phase}}{\text{density light phase}} = \frac{e^2 - l^2}{e^2 - h^2} \qquad (14)$$

In any centrifuge bowl, it becomes apparent e must be greater than l, to provide detention volume for the light phase, and less than x to prevent leakage of the light phase through the heavy-phase discharge ports.

The most common method for controlling the position of the interfacial e line is to use a set of ring dams having h dimensions separated by small intervals. In certain types of centrifuges, nozzles of varying lengths may be used for the same purpose.

For the separation of cream from milk or the concentration of rubber latex, where two discrete phases are not being separated, the adjustment may be made on the light-phase side because this type of separation is extremely sensitive to a slight change in the adjustment.

In the tubular-type rotor of the Super-Centrifuge, the position of the e line may be varied as desired between the limits of l and x by adjusting only the ring-dam size. The problem is somewhat more complicated in the disc type of centrifuge because for maximum efficiency the position of the holes in the disc stack through which the feed is distributed must correspond to the position of the e line. If this correspondence does not exist, the area of the discs between the holes and the e line is not available for separation.

For practical purposes it may be considered that the calculated ring-dam size serves as a starting point and that the optimum position of the e line is arrived at by trial-and-error adjustment. The e line is usually considered to be at its optimum position when the two phases are being separated to the desired degree of purity at some determined capacity and a moderate increment of capacity above this value causes both phases to drop below the desired purity level.

When the optimum ring-dam adjustment has been determined experimentally on a given type of centrifuge such as the laboratory Super-Centrifuge, the results may be translated to any other

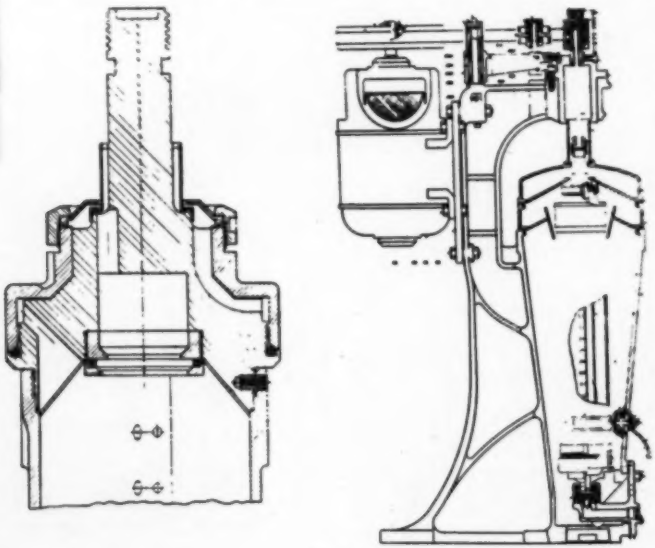


Fig. 4.

type of centrifuge by calculating an apparent value for E on the obviously false assumption that the e line falls at the x dimension in each of the two bowls. While the mathematical integrity of this method is questionable, the results are quite satisfactory.

The Centrifugal Filter. Operation of the centrifugal filter differs from that of the settling-machine type of centrifuge primarily in that the acceleration resulting from the application of centrifugal force is applied only to the liquid phase. In this type of centrifuge, the solid phase is supported on a permeable surface such as a screen through which the liquid phase is free to pass.

The known factors controlling the migration of the liquid phase are its viscosity, the interfacial tension between the liquid and solid phases and the surface area of the solid phase, the length of the path through which the liquid must travel and the free opening between the solid particles available for its travel.

The mathematical relationships governing this flow have never been fully reported. The curve of residual moisture content plotted against time under centrifugal force for several representative materials appears to follow the general formula

$$y = e^{a+bx}$$

in which y is the amount of mother liquor retained on the solid phase, e is the Naperian constant, a and b are constants which are related to the above-mentioned factors and x is the reciprocal of time.

In view of this lack of critical knowledge, the evaluation of the performance of this type of centrifuge is almost entirely on an empirical basis.

In the Sharples laboratories, the performance of its own and competitive equipment is studied on both a pilot plant and full-scale basis. Figure 5 illustrates the equipment available in the portion reserved for the testing of customers' samples. In many cases the information gathered from tests on commercial-scale equipment under test conditions can only be considered indicative, and further long-term testing under commercial operating conditions becomes necessary.

Various types of centrifuges that will be discussed here are as follows:

Super-Centrifuge. This is a tubular type of centrifuge, the rotor of which has a length diameter ratio of between 4.5 and 7.0 to 1. Its operating speed is up to 15,000 rev./min. for the commercial sizes, at which a relative centrifugal force of 16,000 times that of gravity is developed at the I.D. of the No. 26 model, 5-in. rotor, and up to 50,000 rev./min. for the laboratory size, corresponding to a relative centrifugal force of 62,000. All sizes of Super-Centrifuges may be equipped with a variety of rotors designed for specific applications. The basic utility of the Super-Centrifuge lies in the fields of clarification and separation when the quantity of solid phase is relatively low, e.g., under 1%, and when the particle size of the dispersed phase is small so that its high centrifugal force is used to advantage. Another advantage of the Super-Centrifuge is that its performance remains near the theoretical when handling viscous substances, such as molten chicle (chewing gum base) or concentrated nitrocellulose solutions. Presumably because its performance characteristics approach theoretical, it finds wide utility as a classifier, or selective clarifier, for the removal of oversize particles from lacquers, enamels, dye pastes and allied substances and gives a sharp cut-off between oversize and undersize particles. Because of its high relative centrifugal force the solids are well compacted in the rotor and loss of liquid phase with the bowl cake is held to a minimum.

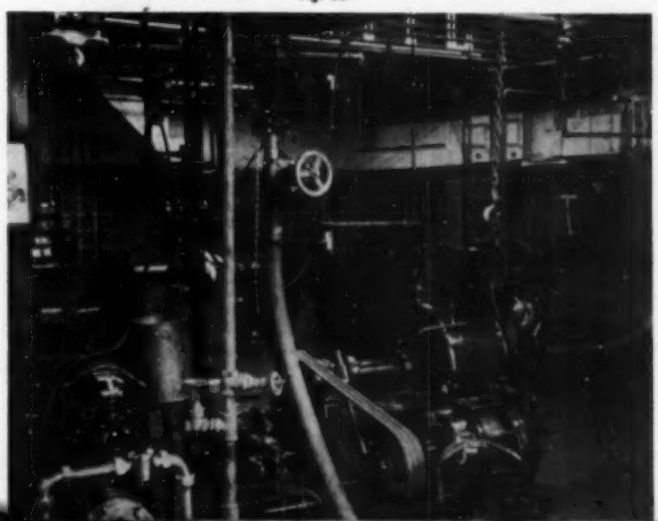
On the negative side, it is a basic requirement of centrifuges of this type that the solids sedimented as bowl cake must be manually removed. The time required for this with the Super-Centrifuge is held to a minimum by its simplicity of design, few parts and light weight.

Fig. 5a.

Disc-Type Centrifuges. Disc-type centrifuges, of which the Sharples *DD-2* (Figure 6), is typical, may be built with considerably higher Σ values. This becomes advantageous when the capacity requirements of a given process or system are high enough to require multiple units, and it is desirable to keep the number of units to a minimum. In addition, because of its low length, diameter ratio, the disc type of centrifuge lends itself well to adaptation to secure automatic or continuous peripheral discharge of solids, particularly those having a degree of plasticity under centrifugal force. In the tubular type of centrifuge these solids would accumulate and require manual removal. The Σ value for a disc-bowl centrifuge may be calculated from Equation (12). It will be noted that the dimensions of the disc stack represent the critical values and that the space outside the disc stack is considered to be useful only for the passage of liquid and the accumulation of solids.

A centrifuge of this type might have 50

Fig. 5b.



discs with an inner radius of 1-⅞ in.; an outer radius of 5-¾ in. and a conical half angle of 45°. The Σ value of its rotor when operated at 6000 rev./min. is 12,430 sq.m.

(A) DD-2 Centrifuge. In this type of disc centrifuge, the solids are retained within the rotor, subject to intermittent manual removal. Because of its larger size and greater complexity of parts than the Super-Centrifuge, the *DD-2* is best suited to the separation of materials containing low concentrations of solids. As a clarifier, this type of centrifuge seldom gives the results indicated by its Σ value. One reason that has been advanced for this is the redispersion of the sedimented solids as they leave the O.D. of the disc stack.

The real utility of the *DD-2* type of centrifuge is in the field of separation, particularly where the dispersed-phase particles are peptized to the point where they can be only highly concentrated or coalesced to a continuous phase with difficulty. On such materials, the relative performance of the *DD-2* in terms of throughput rate approaches the ratio of its Σ value to that of the No. 16 Super-Centrifuge, approximately 5 to 1. In many cases, the observed capacity ratio of these two machines is between 2 to 1 and 3 to 1 and use of the Super-Centrifuge is indicated for economic reasons.

(B) DH-2 (Nozljector) Centrifuge. By modifying the bowl shell of the disc type of centrifuge as indicated in Figure 7, the sedimented solids can be guided to the periphery of the bowl. The relatively short height of this type of bowl permits the creation of a good angle for directing the solids without excessive increase in bowl diameter.

In the simplest form, if the bowl shell is perforated around this peripheral line, certain types of solids will be extruded or washed through the perforations continuously. Since the pressure at the bowl wall is relatively high, of the order of 1000 lbs./sq.in., such openings must be of comparatively small size to avoid excessive liquid flow through them. Furthermore, since these solids will tend to build up to form their own angle of repose, and since if the apex of this angle falls within the disc stack, interference with centrifuge performance results, use of multiple openings, from 6 to 12 is generally found to be desirable. For these reasons and to be compatible with the nominal commercial capacity of such a centrifuge, 1200 to 4000 gal./hr., experience dictates that the openings should be limited to .050 in. ± .015 in. diam. in size. As a further refinement, to minimize power demand, it is customary to direct such nozzles tangentially backward on the principle of a reaction turbine.

In order to utilize a centrifuge of this type on a specific application, the following factors must be considered:

1. Is the capacity of the disc stack to perform the required separation or clarification within the range of the minimum nozzle requirements?
2. Is the major portion of the solid fraction sufficiently plastic, or does it possess a sufficiently low angle of repose, under centrifugal force to permit continuous operation under the conditions outlined above?
3. Is there any fraction of the solid particles of large enough size to clog the nozzles, and if so, what steps can be taken to ensure their removal?
4. Is there any objection from a processing standpoint to the discharge of a relatively large proportion of the heavier liquid phase with the solids contained in it?

(C) DG-2 and DV-2 Centrifuges. For processing problems where sludge concentration is of major importance, or in cases where the capacity of the disc stack is less than the capacity of the minimum tolerable size and number of peripheral nozzles, the disc-nozzle type of centrifuge may be modified further by the introduction of intermittently operated valves on the peripheral nozzles. Two types of valves are in common use. In the *DG-2* centrifuge, the valves are automatically operated by the change in depth of the sedimented-solids layer within the bowl. In the *DV-2* centrifuges, the valves are opened hydraulically by external control. This control may be manual, time cycle, or through a photoelectric cell on the basis of the clarity of the liquid-phase effluent. Since both these types of centrifuges are normally used to obtain high solids concentrations, the characteristics of the solids become of increasingly greater importance, there being less liquid to flush them through the nozzles than is the case with the *DH-2* centrifuge.

The *DG-2* centrifuge will automatically compensate for variations in feed rate and variations in the concentration of solids in the feed and still deliver a sludge of constant solids content. It is, however, quite sensitive to the type of solids it will automatically discharge and its utility is therefore somewhat limited.

The DV-2 centrifuge possesses broader general applicability, particularly in handling solids that under centrifugal force are too fluid or porous to operate the valves of the *DG-2*. On the other hand, when both maximum clarity and maximum sludge concentration are desired, considerably greater care must be given to stabilizing the feed rate and feed composition.

PN-14 and PY-14 (Super-D-Canter) Centrifuges. For many commercial applications, the degree of clarification that can be effected by the Super-Centrifuge is unnecessary and the cost of removing solids from suspension by means of this machine is economically undesirable. The Super-D-Canter (Figure 8) is a continuous clarifier from which the sedimented solids are continuously removed by an internal helical screw conveyor.

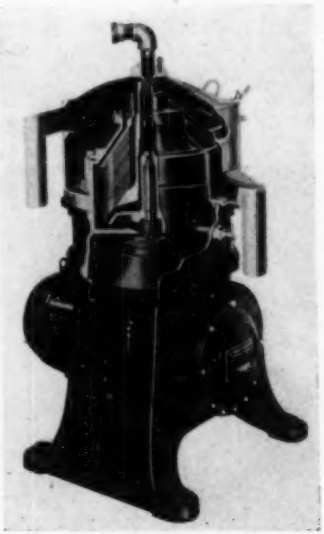


Fig. 6.

The Super-D-Canter has a lower Σ value than the commercial centrifuges so far discussed, 2,620,000 sq.cm. for the PN-14 and 8,300,000 sq.cm. for the PY-14, and its utility is limited to the removal, at commercial rates of above 300 gal./hr., of solids of 2.5 density, which are coarser than about 20μ. At lower throughput rates or when the solids are of higher density, the cut-off point is at a correspondingly lower particle size.

The PN-14 bowl is conical in shape so that the sedimented solids are conveyed across a dry section, or "beach" and given an opportunity to drain before being discharged.

In the PY-14 the bowl is cylindrical and the solids after being conveyed across the bowl are discharged, at least partially, by extrusion.

Use of the PN-14 is indicated when the solids are well-defined particles of sufficient strength to offer at least moderate resistance to deformation under pressure.

Use of the PY-14 is indicated when the sedimented solids are to some extent plastic in nature and can be dewatered to required extent by compression.

Operation of both types of Super-D-Canter is critically affected by the characteristics of the solid phase when it is compacted under centrifugal force. Small-scale tests are therefore of limited use in evaluating the performance of this type of centrifuge.

C-20 and C-27 Super-D-Hydrator. The Super-*D*-Hydrator is an automatic batch centrifuge of the centrifugal-filter type. It consists essentially of a perforated basket, lined with a suitable filter medium, that rotates continuously in fixed bearings on a horizontal axis. In this basket, the normally required operations of loading the centrifuge during which the excess of mother liquor is thrown off, rinsing with one or more suitable washes, spinning to dryness, unloading and, if necessary, rinsing the filter medium are conducted under automatic time-cycle control.

The Super-*D*-Hydrator is made in two sizes with the physical characteristics shown in Table 2. (*See* Fig. 9.)

The capacity of the Super-*D*-Hydrator per load is small and for economic reasons it is usually applicable specifically to systems in which each load may be handled in a relatively short time. On most of its successful applications the over-all time per cycle of this machine is in the range of 0.5 to 2.5 min.

This cycle is made up of the following components which are noted as either variable, where the time element is characteristic of the system, or fixed, where it is a characteristic of the centrifuge.

Load	Variable	
Product Rinse	Variable	
Spin (to dry)	Variable	
Unload	Fixed	0.1 min.
Screen Rinse	Variable	0.01 to 0.1 min.

The time required to change a centrifuge of this type with a load of solids may also be expressed as the time to drain through the basket the quantity of mother liquor associated with this quantity of the solid phase in the feed slurry.

The economy of the use of the Super-*D*-Hydrator, or any similar centrifugal filter is favored by operation on a system having a maximum solid-liquid ratio. On the other hand, the design of the Super-*D*-Hydrator requires a fluid feed which will flow into the centrifuge through a pipe at an adequate rate when the feed valve is opened, and this factor controls the limiting permissible concentration of the feed.

Particles of the solid phase must be large enough and have sufficient strength to resist deformation so that under the operating conditions there will be ample connected void space between them for the free passage of the mother liquor.

In order to ascertain which type of centrifuge is applicable to a specific problem, a certain minimum amount of information regarding the system that is to be processed must be made available, such as:

1. Is the problem simply one of removal of a solid phase from one or more liquid phases?
2. Must the several liquid phases also be separated?
3. What is the nature of the solid phase in terms of—
   a. Composition, or equivalent chemical/physical characteristics;
   b. Particle size—average and distribution;
   c. Density;
   d. Amount present in the system, and probable maximum and minimum limits;
4. What is the nature of the liquid phases (or phase) in terms of the following:
   a. Composition, or equivalent chemical/physical characteristics.
   b. Density, and temperature/density gradient.
   c. If two or more liquid phases are to be separated, what is the proportion of each present in the system, and to what extent will it vary under normal processing conditions?
5. Within what temperature limits can the system be handled for economic and practical reasons, and from the standpoint of product quality?

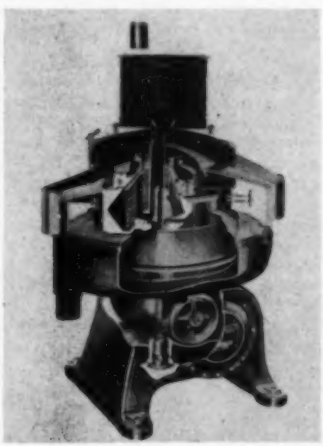


Fig. 7.

TABLE 2.

	C-20	*C*-27
Diameter at filter surface	20 in.	27 in.
Width of basket	10 in.	13.5 in.
Depth available for solid phase	2-¾ in.	3 in.
Area of filter surface	628 sq.in.	1142 sq.in.
Maximum speed	2100 rev./min.	1800 rev./min.
Maximum centrifugal force	1193 × *G*	1242
Connected power	20 hp.	40 hp.
Weight, solid phase per load per apparent bulk density in pounds per cubic foot	Up to 1	Up to 2.46

6. What results are desired and required in terms of capacity, and degree of purification of the several components?

The centrifuge can be considered only a satisfactory answer to a specific problem when it can be shown to give the results required under No. 6 at a reasonable cost.

Usually the preliminary discussion on a particular problem will narrow it down to one of three fields: clarification, separation, or crystal dehydration.

To facilitate laboratory tests questionnaires,* covering the specific information required for testing samples in each of these categories, are used. Information thus made available serves to define further the type of centrifuge applicable to the specific problem so that before any test is begun the type of centrifuge whose performance is to be evaluated is fairly well established.

Practical experience has indicated that commercial Super-Centrifuge performance can be predicted with a high degree of accuracy from laboratory Super-Centrifuge test data within the capacity limits previously defined. Within these same capacity limits the separation performance of the disc type of centrifuge can also be predicted with a probable accuracy of ±25%.

Small-scale tests will give some indication of the suitability of the peripheral discharge-disc type of centrifuge for continuously or automatically handling the separated-solid phase, but such tests can never be regarded as conclusive unless a substantial background of experience exists on a specific application.

Numerous attempts have been made to extrapolate laboratory scale test data in terms of Super-*D*-Canter performance. These have been almost uniformly unsuccessful, although recently a small-scale model of this centrifuge has been made available that holds some promise.

Even on ideal test systems, such as preclassified clay in water dispersion, there is a substantial difference between the performance values for the various settling-machine types of centrifuges as calculated from their geometry and the actual results that are obtained from them. This may be defined as an efficiency factor. Experience has indicated that this performance factor is subject to still further modification when the more complex systems that are usually met with commercially are to be processed.

Table 3 indicates this relationship and shows the magnitude of the variation from experimental results, that is likely to be encountered, as well as the range of usefulness.

In order to correlate all the performance factors of the Super-*D*-Hydrator, a test on a *C*-20 on a sample of sufficient size to run at least five successive cycles is essential. For preliminary study of any given system, filtration tests on a Buchner funnel give an indication of drain rate that may be of some utility. More explicit data may be obtained from tests on a small batch basket centrifuge.

Theoretically, the instantaneous drainage rate is a function of the cake thickness. In actual practice, the average drainage rate over the loading portion of the cycle has been found to correspond rather closely to the instantaneous drainage rate through a cake thickness which is 50% of that of the Super-*D*-Hydrator when fully loaded or 1-½ in. in the case of the *C*-20. Such a cake can be conveniently built up on a batch 12-in. basket centrifuge, rotated to give the centrifugal force of the Super-*D*-Hydrator, and accurate drainage rate studies can be made on 10-lb. samples.

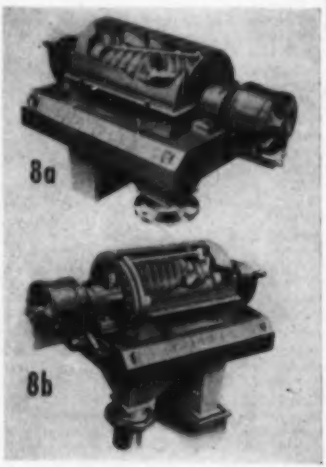


Fig. 8.

* The information sheets for the various categories of centrifugal applications are available from Sharples Corp., Philadelphia, Pa.

It will be seen from the foregoing that the direct and complete evaluation of commercial centrifuge performance, on a system that has not previously been studied on a commercial scale is only possible under well-defined conditions from laboratory tests. In many cases it must be considered that such tests serve to indicate whether a full-scale test is worth making and whether such a test can be made in the laboratory or whether it should be made in the field.

Laboratory scale tests are also useful to indicate the deviation, if any, of the sample from a similar material that is being centrifuged successfully and in this specialized category can be considered of great utility for evaluation of commercial performance with a high degree of accuracy.

In a somewhat different category, laboratory tests may frequently be valuable to determine critical operating conditions such as temperature, chemical pretreatment and the like on a comparative rather than an absolute basis.

Several possible centrifuge applications and the extent to which laboratory scale tests on them can be used to evaluate commercial centrifuge performance can be considered.

Tar Dehydration. Tar emulsion as obtained from water gas generators is a three-phase system composed of the tar itself, an aqueous phase having a density very close to unity, and up to 20% on a dry basis of free carbon ranging in size from submicroscopic to macroscopic bits of coke. The tar itself is a rather complex mixture resulting from the thermal decomposition and possible polymerization of the oil used to enrich the water gas. To be commercially acceptable, this tar must be dehydrated to 2% or less residual moisture content.

The dehydration of water gas tar emulsions is one of the earliest centrifugal applications. Until 20 years ago, relatively light gas oil was generally used for gas enrichment and in some few cases is still used today. The resultant "tar" is quite fluid, low in insoluble solids content and its density is less than that of the aqueous phase. Such emulsions can readily be resolved on the No. 16 Super-Centrifuge.

In a typical case, a sample of light water gas tar emulsion at 54% moisture content was received for test. Based on previous experience, it was decided to operate at 200° F. and tests were made on the laboratory Super-Centrifuge at this temperature using a separator bowl. A No. 8.5 ring was selected which was changed to a No. 8 before taking any samples because of the fact there was a considerable loss of tar to the heavy phase under the first condition.

Samples were taken of the effluents at feed rates of 525 and 750 ml./min. after approximately 2-min. operation to allow the centrifuge to come to equilibrium. Both samples of the light phase tar were found to contain 0.15% moisture, well under the requirement of 0.5% residual moisture at a rate corresponding to his maximum production of 250 gal./hr. of emulsion. The solids removed as bowl cake amounted to 0.6% by volume of the emulsion, indicating that the No. 16 Super-Centrifuge bowl would require cleaning after centrifuging 167 gal. of emulsion on the basis that this bowl will hold one gallon of dirt.

A No. 16 Super-Centrifuge was installed on this job and its performance confirmed the laboratory estimates. At an average feed rate of 175 gal./hr., the tar discharges at less than 0.25% moisture and the bowl is cleaned once an hour.

When heavy oil, such as Bunker *C*, is used for gas enrichment, the problem becomes considerably more complex. A complete system has been developed for dehydrating such emulsions which includes the elements of feed pump, heater, self-cleaning strainer and Nozljector. The unit capacity of this system is controlled by the size and number of discharge nozzles in the centrifuge to the range of 800 to 1100 gal./hr. of dehydrated tar. For practical reasons the operating temperature is fixed within the range of 205° F. ± 5° F.

Variables which control dehydration of a given emulsion to the required extent are:

1. Moisture content of tar emulsion.
2. Relative specific gravities of tar and water phases.
3. Viscosity of emulsion.
4. Solids content of tar.

As an overriding control of the above, the extent to which the emulsion can be separated on a laboratory Super-Centrifuge under specific operating conditions is also determined.

The moisture content is determined by distillation in a Dean-Starke apparatus on a 20-g. sample using xylene as the diluent. The moisture content of the feed emulsion should not exceed 45% for satisfactory operation of the commercial unit.

Relative densities of the dehydrated tar and separated aqueous phases from the laboratory Super Centrifuge are determined with a hydrometer at 98° C. Obviously this method does not give absolute values, but it does give sufficiently accurate relative values for the purpose. The ratio of densities by this method must not be less than 1.10.

Viscosity measurements are made on the emulsion at 98° C. using a Stormer viscosimeter. Readings are made with both 50 and 150 g. weights and translated to absolute viscosity. Any significant difference in the viscosity reading with the two different weights is cause for closer examination of the sample since experience has indicated that emulsions that exhibit such a difference are likely to be difficult to separate commercially. For satisfactory separation, the observed viscosity by this method should not exceed 0.6 poises at 98° C.

The total solids content, free carbon, is determined by drying a sample of tar in the oven at 210° F. overnight, diluting it with 20 volumes of benzene and filtering through a medium Alundum crucible and then refluxing the crucible under nitrobenzene to remove the asphaltic materials. For satisfactory operation, it is considered necessary for the free carbon content on a dry tar basis to be less than 20% by this method.

Another critical value is the amount of particles coarser than .015 in. diam. Such particles must be removed on the self-cleaning strainer to avoid clogging of the Nozljector nozzles. The technique employed is to dilute a dry sample of the tar with nitrobenzene and wash it through a 50 × 50 mesh Tyler screen. After drying on the screen, the particles are brushed off the screen and weighed. For satisfactory operation of the centrifugal tar dehydration process, the quantity of plus .015 in. particles should not exceed 0.1%, dry tar basis.

As a final test, a one-gallon sample of the tar emulsion is heated to 200° F. and run through the laboratory Super-Centrifuge, using a separator bowl with a No. 8.5 ring dam and operated at 16,000 rev./min. at a feed rate of 1000 ml./min. A period of 2 min. is allowed for the centrifuge to reach equilibrium and then a sample taken of each of the separated phases. Under this test condition, the tar should be at less than 2% residual moisture content and the aqueous phase should contain not more than 10% of tar.

Experience gained from some 20 operating units indicates that a tar emulsion showing less than the noted critical values in this series of tests can be handled in the available commercial equipment. In this particular example, the process, the equipment and the operating techniques have been established. The laboratory tests serve to correlate a new or unknown sample with other similar materials that are being processed successfully.

TABLE 3.

	Σ Value in Square Meters		
	Calculated from Geometry	From Experimental Data on Classification of Ideal Systems	Extrapolation on Commercial Systems (from Supercentrifuge Tests)
Laboratory Supercentrifuge			
@ 10,000 rev./min.	54	54	54**
@ 16,000 rev./min.	138	138	
@ 23,000 rev./min.	285	285	120*
@ 50,000 rev./min.	1350	1350	Not used
No. 16 Supercentrifuge			
@ 15,000 rev./min.	2520	2520	2520
No. 2 Size Disc Centrifuge			
52 Discs—35° angle @ 6000 rev./min.	16000	9100	8300 to 16600
50 Discs—45° angle @ 6000 rev./min.	12430	6750	6300 to 12430
Super-*D*-Canter			
DV-14 @ 3250 rev./min.	441	274	274**
DY-14 @ 3250 rev./min.	830	555	555**

* Within the capacity limits previously specified to No. 16 centrifuge or No. 2 size disc centrifuge.
** These relative values only apply up to a rate of about 1 l./min. on the Supercentrifuge and the extrapolation, therefore, only holds for relatively low throughput rates on the Super-*D*-Canter.

Similar arbitrary tests have been developed for a number of other applications.

In many cases there is no such detailed background of knowledge and the laboratory tests must indicate more directly the best type of centrifuge, any mechanical deviations from standard construction for this type and the materials of construction as well as the estimated performance. Frequently this laboratory scale test will serve only to indicate whether the problem is sufficiently attractive to be explored on a large enough scale to obtain the required information.

In a typical example of this category, it was desired to remove 4% of suspended barium oxide from a heavy oil having a viscosity of 100 ssu. at 210° F. and a density of 0.96 at the normal operating temperature of 325° F. No information was available as to the particle size of the barium oxide particles except that their removal by filtration was "difficult and accompanied by a material loss of oil." The quantity to be handled was 8160 gal./day containing 2400 lbs. of solids.

The description and appearance of the sample suggested that either the *DV*-2 or *PV*-14 centrifuges might be applicable. A portion of the oil was heated to 325° F. and run through the laboratory Super-Centrifuge using a clarifier bowl operated at 16,000 rev./min. at a nominal rate of 400 ml./min. The oil discharged was entirely satisfactory but the solids, which amounted to 1.2% by volume of the sample, were deposited as a hard compact cake in the bottom of the bowl and were obviously too hard to discharge through valves of either the *DV*-2 or *DG*-2 centrifuge.

A second portion of the oil was heated to 325° F. and run through laboratory Super-Centrifuge using a clarifier bowl operated at 10,000 rev./min. at a nominal rate of 500 ml./min. This centrifuging removed 86.5% of the suspended solids and left a bowl cake that appeared to be of a type that could be discharged from the *PV*-14 Super-*D*-Canter.

This result was confirmed by a subsequent full-scale run on the Super-*D*-Canter, which indicated that 90% of the solids was removed at between 250 and 280 gal./hr. and 85% and 500 gal./hr.

In the example cited, the laboratory test served to screen the problem and indicate which centrifuge had a possibility of working without yielding specific operating data. Perhaps the major portion of the samples studied in the Sharples laboratories fall in this category.

The importance of securing a representative sample for tests cannot be overestimated. Frequently the prospective customer tends to overlook this factor unless it is brought directly to his attention.

The problem of clarifying 100 gal./hr. of clear soup at 160° F. to remove "approximately 1% insolubles" was brought to the laboratory together with three one-gallon cans of the soup before clarification. Satisfactory results from the standpoint of clarity could not be obtained when using a clarifier bowl on the laboratory Super-Centrifuge, even at rates as low as 200 ml./min. This poor clarity was found to be due to the presence of a small amount of floating fat particles and when a separator bowl operating at 22,000 rev./min. was used to skim off the fat, an entirely satisfactory degree of clarification was obtained at a rate of 500 ml./min. at the specified operating temperature.

On the basis of this test a No. 16 Super-Centrifuge was installed at the customer's plant. Satisfactory results could not be obtained at any capacity, and the original laboratory tests were rerun in the plant. At the plant, it was found to be impossible to duplicate the original tests. After some discussion, it was brought out that the samples originally tested had been preserved with a small amount of formaldehyde which had coagulated the colloidal protein and completely altered the problem.

Laboratory tests on centrifuges fall in three definite categories as follows:

1. The somewhat limited category where the laboratory results can be translated directly into definite commercial performance as exemplified by the correlation between the laboratory and No. 16 Super-Centrifuges within the limits previously specified.
2. Screening tests to eliminate negative possibilities, to indicate the type of centrifuge probably applicable, and the size of sample probably required critically to evaluate the performance of the commercial size centrifuge. Such tests also indicate whether the full-scale or pilot plant runs should be made in the laboratory or in the customer's plant.
3. Comparative tests where a background of process application knowledge has already been built up and the requirement is to compare a new sample with material that is already being successfully handled commercially.

In making either laboratory or field tests to evaluate the performance of any centrifuge on a given material there are three critical factors, the importance of which cannot be overstated:

1. Any hazards that may exist in handling the material; this will serve to determine the type of enclosure and drive required and may even control type of centrifuge that can be used.
2. The corrosiveness of the system and effect of metallic contamination on the materials being handled; these will control the materials of construction of the centrifuge and related equipment.
3. Procurement of an accurate sample; the performance of a centrifuge, or any other piece of process equipment, can only be evaluated in terms of the sample that is being tested. Unless the sample corresponds in every respect to the material that is going to be processed or unless the variations from it and their effect are known, significant results cannot be obtained.

Literature Cited

1. Svedberg, T., and Pedersen, K. O., "The Ultracentrifuge." Oxford: Clarendon Press. (1940).

Discussion

D. W. Collier (The Sharples Corp., Philadelphia, Pa.): The research and development departments of the Sharples Corp. frequently have the problem of developing processes in which a centrifuge plays a major role. Therefore, I will point out some extensions of the principles Mr. Ambler has set forth which are useful in process development.

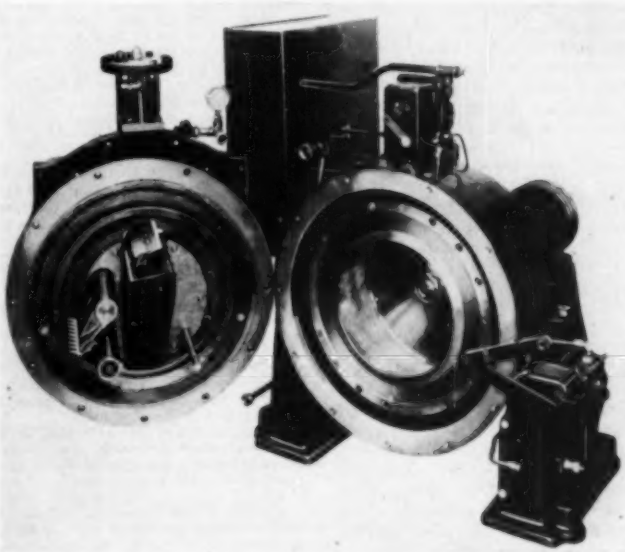


Fig. 9.

The first suggestion is to plot the results of any centrifuge clarification study as flow rate through the centrifuge vs. the fraction of the solids in the feed which are left unsedimented, on logarithmic probability paper, in the indicated order. Usually, such a plot will be a straight line over the range of interest, i.e., about 1½ cycles of flow rate variation, but in some cases as high as four cycles. Such a plot allows easy interpolation and less dangerous extrapolation, if you must—in order to determine the effect of other process variables on the centrifuge performance, or vice versa, and for use in arriving at the final optimum process design.

The second suggestion is to plot the flow rate as a function Q/Σ where Q is the flow rate in any convenient units and sigma is the performance factor described in this paper as determined experimentally for the particular centrifuge on an ideal system expressed in units consistent with Q. Such a plot makes it relatively easy to transfer results from one centrifuge to another and in process development this usually means from the laboratory-size centrifuge to commercial-size centrifuges. According to the principles in this paper, if the system is ideal, that is, has a stable particle size and its clarification properties are determined by the settling power of the centrifuge, all centrifuge performance data should fall on the same line as Q/Σ vs. fraction of solids unsedimented.

The final slide shows data on the clarification of protein particles from melted hog fat, in which data from the laboratory machine (the circled points), data from *DV-2*—a valve discharge disc machine with externally controlled valves, and the *DG-2* where the valves are controlled by the depth of solid sedimented in the bowl, all fall on the same curve of Q/Σ plotted on the log scale vs. the fraction unsedimented plotted on the abscissa.

These data correspond to flow rate variations between less than 2 gals./hr. on the laboratory centrifuge to more than 1000 gals./hr. through the *DV-2*. One word of caution is necessary here —when the curve for the particular machine deviates from a straight line, it is an indication that the sigma correlation has broken down, and therefore, extrapolation from one machine to another is recommended only on the straight portion of the curve.

In addition to allowing easy transfer of information from one machine to another, and we do this by taking the desired recovery and the sigma of the machine in question, and multiplying the ordinate on the curve to get the flow rate through the machine in question—such plots allow a pointing out of the deviations from ideality which occur in some systems. A few illustrations might be given here of some types of deviations.

The first is where the system lies within the clarification power of the conical Super-*D*-Canter—the machine with the scroll in it but when the compacted solids have difficulty in scrolling against the centrifugal force. In such cases three tests can be used to point out this difficulty. In the first one, the Q/Σ points from the *P*-14 —the Super-*D*-Canter will fall below the curve on the same system which has been determined in the laboratory machine. For instance, if this were a laboratory curve we would get a curve that would fall below it on the Super-*D*-Canter.

In the laboratory machine the capacity of the centrifuge is limited only by the settling power of the centrifuge. In the *P*-14 the settling power performance is lowered by any difficulties in scrolling of the material.

The second test is that if you determine the curve existing when the *P*-14 is run at its nominally rated revolutions per minute—then run the system through the *P*-14 at a lower rev./min. and plot the results again as Q/Σ where sigma is corrected for the lowering of the rev./min., which in settling power will be lowered in the proportion to the square of the speed of the rotor—if those points fall above the original curve at the nominally rated rev./min. this again indicates difficulty in scrolling because we usually find that if a system is plastic under centrifugal force, the higher the centrifugal force the more difficult it is to scroll the solids out of the conical bowl.

The third test is to change the temperature of the feed. In ordinary settling, as you noted, from the effect of the liquid viscosity on the settling power of the system—you would expect an increase in temperature to increase the capacity of the centrifuge. If such an increase in temperature does not change the position of the *P*-14 clarification curve, or lower it, this is again an indication that scrolling is the difficulty and the use of a different machine such as the cylindrical bowl *P*-14 or a valve discharge centrifuge is indicated. In some cases where scrolling is completely controlling, and the system is one which is easy from a sedimentation standpoint, better results are obtained below the nominal rev./min. in the *P*-14 bowl.

The second case where we have deviations from ideality, is where the solids are deflocculated or emulsified in the centrifuge inlet. In such cases two tests by this method of plotting point up this difficulty. The first is that if you plot such a curve from a bottle centrifuge and then plot it from a continuous centrifuge such as a laboratory machine, the continuous centrifuge curve will fall below that of the bottle. Now ideally, they should fall in the same curve and since the bottle centrifuge usually does not break up the solids this is an indication that the continuous centrifuge inlet conditions are fracturing the solids as you feed them to the machine.

The second test is that variations in the inlet configuration, among the various standard variations which exist, produce variations in the capacity curve of the centrifuge. On an ideal system, these standard inlet configurations produce no variations in the position of the Q/Σ vs. % sedimented curve. If they do, this is again an indication that you are having a solids fracturing problem and in such cases attention must be paid to inlet design of the centrifuge in order to obtain optimum performance.

R. Katzen (Vulcan Copper & Supply Co., Cincinnati, Ohio): The problem of selection of the nozzle orifice dimensions on both the disc-type centrifuge and on automatic units, is an important question. It is one thing to make a separation in the centrifuge and another to get the separate products out. In separating thickened materials such as yeast creams from aqueous suspensions —the separation itself is not too complicated but the selection of the proper nozzle sizes to discharge the thickened slurry, becomes a critical one. In our experience it turns out to be quite a time-consuming trial-and-error proposition.

Is it possible, Mr. Ambler, to make some sort of correlating tests in laboratory centrifuges whereby a preliminary estimation of nozzle sizes could be determined and so reduce some of this trial-and-error work in plant operation?

C. M. Ambler: The problem of exploring on a small scale the factors controlling the critical operation of a nozzle-discharge type of centrifuge has never been fully solved and full-scale test work is usually necessary.

As a guide to full-scale test work certain values can be determined within reasonable limits. For instance, for a given centrifuge the Σ is either known or can be calculated. The Q/Σ ratio of the material to be processed is determinable from small tests within the limits stated in Dr. Collier's comments. The discharge volume of the nozzles of the given centrifuge can be determined in terms of their diameter and number.

Given this much information on yeast, which is handled frequently in centrifuges of this type, the possible through-put rate for satisfactory recovery and the concentration attainable can be calculated with reasonable accuracy.

However, small-scale tests will not show accurately whether the sedimented solid phase of a new system will discharge continuously without building up in the bowl to the point of interfering with its operation. This is particularly true of a heterogeneous system when there is a relatively small fraction of the solid phase which may pack under centrifugal force and accumulate in the bowl at a high angle of repose.

In general, it may be said that the smallest usable nozzle must be at least twice the diameter of the largest solid particles that are intended to pass through it. On most concentrations it is better to operate with a larger number of small nozzles than to try to run with a few large nozzles.

(Presented at White Sulphur Springs, (W.Va.) Meeting.)

SHOULD CHEMICAL ENGINEERING BE EXPORTED?

EDGAR L. PIRET

University of Minnesota, Minneapolis, Minnesota

AMERICANS regard chemical engineering as a well-established and accepted branch of engineering. We are not particularly startled when our national statistics show some 30,000 engineers practicing their profession, more than 60 accredited schools of chemical engineering, some 2,500 students graduated in 1949, 100 Ph.D.'s awarded in the same year and some 10,000 or more members of the A.I.Ch.E.

This is not at all the situation in Europe. In fact, the recounting of such figures astounds a European audience of chemists, engineers and educators, most of whom today have no knowledge of the training of the chemical engineer and of the importance of his role in the American process industries. These are the industries which, as we know well, because of technical skill, spirit of enterprise and physical development, constitute one of the strongest factors in the economic strength of our country and in the welfare of its people. They are also the industries whose strong development in Europe is important to its future and welfare.

The Profession in America and on Continent—A Striking Contrast

Today the contrast between the status of the profession of chemical engineering as it exists in America and as it exists on the Continent remains surprisingly great. The differences in educational programs, objectives, and methods of teaching students in preparation for the chemical and process industries are not less surprising. Many American chemical engineering educators do not realize that the lack of understanding across the ocean, especially in the field of technical education, is as large, if not larger, than that existing in the political field and that frequent exchanges of views in this area, as well as in the areas of engineering and industrial methods, are needed.

On the Continent, one can count on the fingers of one hand the educational centers giving what approaches our concept of chemical engineering education. At not one of these do the students receive the integrated training in unit operations theory, problems, laboratory, chemical engineering thermodynamics, etc., which we consider important to chemical engineering.

EDITOR'S NOTE

The author of this short article spent several months last year as a Fulbright research professor at the universities of Nancy and of Paris, bringing to these centers of learning the American philosophy of chemical engineering. For him it was a return to familiar scenes, for part of his early education was obtained in Europe also. From this background, and also from his educational experience as professor at University of Minnesota and as a consultant to industry, he speaks on a problem complex in scientific as well as cultural and economic implication. Originally scheduled for our Opinion and Comment page, the length (and breadth) dictated its use as an article.

The professional status, the industrial practice and the educational methods existing in the field of chemistry, and in the other branches of engineering on the Continent and in America, do not present nearly as sharp a contrast as in chemical engineering. This divergence probably is a consequence of the fact that these fields are appreciably older than chemical engineering.

War's Effect on Chemical Engineering Progress

Then, too, the great wars of our times, with their enormous waste of the best in human and material resources, and of time, occurred during the growth period of chemical engineering in America, and weighed especially hard on our European allies. The retarding influence of strongly entrenched interests and rigid tradition working within the universities and technical schools, and even in the industries themselves, has played perhaps a more important role. Be that as it may, today, there are men on the Continent who are working hard and who are determined to bring about the changes and the additions necessary to develop, as rapidly as possible, what is, on the Continent, practically an unknown branch of engineering. They face difficulties which, while serious, are not insurmountable.

Faced with this development in their profession, the American chemical engineers should ask themselves whether or not their responsibilities require them to aid such initiatives and to study just how individuals or professional societies, can contribute toward the success of these efforts.

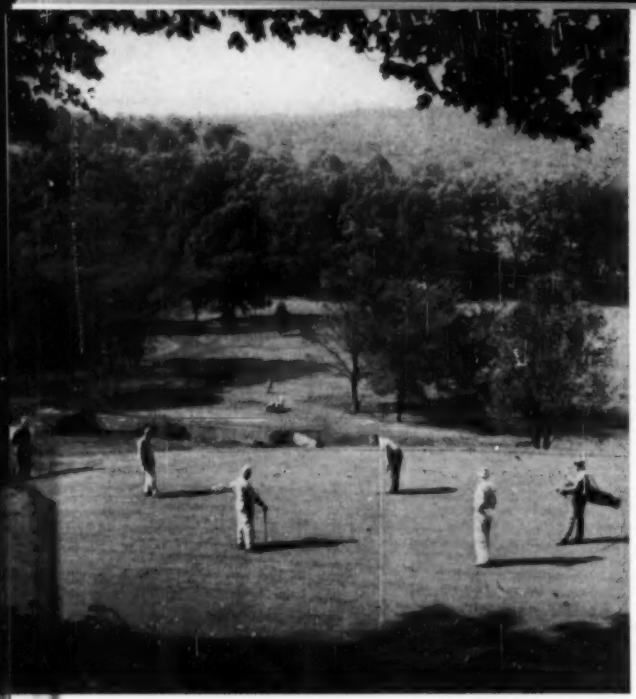
As proud and certain as we are of the importance of our branch of engineering and of its contributions to the growth of our national economy, we might feel that the above contrast constitutes one index of the present technical stature and strength of these two areas of civilization and just let it go at that.

But such a viewpoint in my opinion is contrary to all but a narrow, restrictive interpretation of the social and professional responsibilities of the engineer to his country and to mankind. And, looking at it even from a selfish point of view, we seem to be finding out that the democratic world must grow economically strong in all of its parts if it is to survive. And for survival the Western world depends upon the contributions of the technical man, particularly in the elimination of economic and material misery.

We may also expect, with the development of chemical engineering in Europe, a greater flow to America of new ideas and concepts in this field. It is not so very long ago, after all, that the flow of scientific thinking was entirely in the westerly direction.

Potentialities of America's Contribution

The contrast in the chemical engineering profession and education clearly shows a direction in which America can contribute to the development of the long-time technical and economic strength of its allies. There is a job to be done by the American Institute of Chemical Engineers and by our chemical engineering educators in promoting the strength of our world and in widening the horizons of our profession. To indicate directions in which we can help, we need only to mention the importance of having well-supported fellowships available to the best of European students, the need for professorial exchanges, and perhaps also the occasional presentation in easily available and readily interpreted forms, of what we consider to be our best educational programs and teaching methods.



▲ French Lick boasts two golf courses, plus many other facilities that should appeal to the visiting chemical engineers for after-meeting recreation.

CONFERENCE ON VACUUM ENGINEERING FOR FRENCH LICK

A THREE-DAY conference on vacuum engineering will feature the French Lick national meeting of the Institute, scheduled for May 11-May 14. Wheaton W. Kraft, vice-president of The Lummus Co., New York, is chairman of the technical program and has planned to cover only the one subject during the three days. This idea follows the successful plan of A.I.Ch.E. begun last year at White Sulphur Springs, a resort-type meeting devoted to a single subject. According to preliminary plans 16 papers will be presented covering all phases of vacuum engineering. These will range from corrosion problems encountered in steam jet vacuum equipment to a discussion of the transport of vapors under low residual gas pressures.

The intention behind the program, according to the program chairman Mr. Kraft, is to give to chemical engineers an opportunity to explore the field of vacuum technology from both the theoretical and practical standpoints. "At such specialized meetings," said Mr. Kraft, "the opportunity for serious consideration of new techniques is greatly enhanced by being at a resort where the experts will be readily available for questioning and interviews, not only during the technical sessions, but after the sessions have closed." As stated previously this is in line with the Institute's policy of holding resort meetings, and concentrating on specific chemical engineering subjects.

Technical Program

Other papers given during the meeting will cover practical design problems for vacuum systems operating at low pressures; selection and use of vacuum pumping systems; methods of measuring low pressures; entrainment in petroleum refinery stills; maintenance of vacuum pump, lubricating and sealing oils; multistage ejectors and high vacuums; and the incurred savings when high vacuum technique is applied to concentration. The present plans of the program committee call for morning and afternoon sessions on Monday, May 12, and morning sessions on Tuesday and Wednesday, May 12 and 14.

A full program of the subjects covered will be given in the April issue of "C. E. P."

Wheaton W. Kraft, vice-president of The Lummus Co., is technical program chairman of the French Lick meeting. This is the second major symposium he has organized for the A.I.Ch.E., the other, covering the techniques used in processing viscous materials, was held in 1950 at the Columbus (Ohio) annual meeting.

Hotel Accommodations

The main technical sessions will be held in one wing of the hotel, in a huge hall with a capacity of 1200. As for rooming accommodations, the hotel management states that it can handle easily up to 1000 persons in the 600 rooms that are available. Rates on the American plan (meals included) are for a single, $16 a day, and doubles will range from $14 down to $10 per day, a person.

Transportation

The Baltimore and Ohio Railroad, and the Monon serve the hotel, the latter having a spur that leads right to the hotel. A private airport is near for those arriving in company planes, and bus routes are run from nearby Indianapolis and Louisville. From New York, the B. & O. has a daily late afternoon train, making direct connections in Mitchell, Ind. with the Monon Motor Coaches, arriving at the hotel just before noon. From Detroit and St. Louis the connections are similar via the B. & O. through Mitchell, Ind. From other southern points the Southern Railroad, the Louisville and Nashville and the Illinois Central Railroads connect at Louisville with Greyhound Motor Coaches direct to the hotel. For those using the New York Central, a Greyhound bus must be taken at Indianapolis for connection to French Lick.

Recreation

There are facilities at the resort for golf (two courses are available), riding, archery, badminton, tennis, billiards, bowling and skeet shooting. In addition the area is noted for its mineral springs and a medical staff is in attendance for advice.

Registration at the meeting will be at the following fees: Active and Associate members, $3.00; Junior members, $2.00; Students and members of Student Chapters, $1.00; Nonmember chemical engineers, $6.00; Other guests, $4.00; Ladies, $3.00.

TYGON

Versus HNO_3

NITRIC acid on the attack is hard to stop. However, there are good defenses available and one of the best is the versatile group of TYGON plastic compounds. Properly used, TYGON—as tank lining, gasketing, flexible piping, or protective coating—displays excellent resistance to nitric acid over a useful range of concentrations and conditions.

Essentially, TYGON consists of selected polyvinyl resins skilfully modified with other materials to give the optimum in chemical resistance and desirable physical properties. Solid TYGON is available in calendered, extruded, or molded form. Liquid TYGON is available as a plastisol or as a solvent type paint. Such variety in form permits the best use of TYGON for a specific application.

In calendered form, TYGON is generally used as a material of construction. Volume use is as a lining for tanks and tank covers, drums, hoppers, fume hoods, and fume ducts. Widest use is as cut gaskets and washers for sure, durable seals in all types of chemical process equipment. As a 3/32" calendered sheet, TYGON resists nitric acid in concentrations up to 30% by weight and temperatures as high as 150°F. Permissible concentration depends upon the temperature of service, with only the lower strength solutions being advised for the higher temperature. When cut into gaskets, calendered TYGON can be used with practically any concentration of the acid as the slight swelling and other changes that take place in the small exposed area serve only to make a tighter seal and have very little effect on the protectability or functioning of the entire gasket. Either as sheet or gasket, TYGON is not recommended for service with mixed or nitrating acids without previous consultation with U. S. Stoneware engineers.

In extruded form, TYGON is used primarily as a medium of transmission. However, extruded solid cord, channel, or tape are also used as materials of construction.

Smooth walled, light weight and flexible, TYGON Tubing, in sizes up to 2" ID, is used in a great number of laboratories and plants for the safe, efficient transmission of liquids, gases and semi-solids. In many plants, TYGON is being used as flexible piping in permanent or temporary transfer lines, as flexible connections, as line desurgers, as ports on chemical pumps and filters, or as syphon hoses.

As tubing, TYGON is resistant to nitric acid in any concentration and at temperatures up to 130°F. For brief, intermittent exposures, the temperature limit can be increased to 150°F. However, in any service with nitric acid, the life of TYGON Tubing is directly dependent upon the length of exposure and the care given the tubing. Short periods of service and frequent cleanings are suggested. The counsel of our engineers is recommended.

In molded form, TYGON sees service as gaskets, grommets, washers, stoppers, handles, bumpers and special fittings. Where necessary, it can be reinforced with glass fibers for added strength. With or without reinforcement, molded TYGON generally is suitable for service with nitric acid of any concentration and temperatures as high as 150°F. Specific limitations depend upon the size and design of the piece, the temperatures and pressures involved, and other conditions of service. Use with mixed or nitrating acids is not advised without consultation.

As a paint, TYGON, in contact with nitric acid, must be considered in the light of the limits of a thin film. Generally, a TYGON paint film is resistant to the fumes of nitric acid in all concentrations and up to 150°F. However, contact with highly concentrated hot nitric acid is to be avoided and any spillage, regardless of concentration, should immediately be washed off. The minimum system recommended for any service with nitric acid consists of a primer and no less than five top coats.

As a plastisol, TYGON finds use as a heavy duty coating and in the casting or "slush" molding of flexible fittings and parts. For coating work, it can be applied by dipping or spraying on hot metal, and, then, fusing. Resistance to nitric acid varies, depending upon the thickness of the coating deposited.

In any of its forms, TYGON provides low cost protection and high degree of safety in the handling of not only nitric acid and related chemicals, but a wide range of other acids, alkalies, oil, greases and water.

TYGON plastics

In addition to TYGON in its various forms, we also manufacture a number of other materials capable of handling nitric acid in any concentration and under all types of operating conditions. These products include chemical stoneware and porcelain, acid proof brick and cements, and other organic linings and coatings.

Why don't you submit your corrosion problem, today? There's no obligation and we'll be pleased to be of assistance. So write, now!

THE UNITED STATES STONEWARE CO., Akron 9, Ohio

MANUFACTURERS, ERECTORS OF CORROSION-RESISTANT EQUIPMENT SINCE 1865

A.E.C. PUBLISHES ENGINEERING SYMPOSIUM

As an aid to industry in participating in the Atomic Energy program a new publication of the Atomic Energy Commission has now become available to the public.

Entitled "The Role of Engineering in Nuclear Energy Development," the publication is a report of the proceedings of a symposium on nuclear engineering held at the Oak Ridge National Laboratory in September, 1951. The symposium was sponsored to accelerate education in nuclear engineering throughout the nation's technical schools. The papers contained in this report "present enough declassified information in the field of nuclear engineering to help engineering educators more intelligently decide how best they can discharge their responsibility to the country's nuclear energy effort."

Seventeen separate papers are contained in this 509-page report on such broad phases of atomic energy as "Engineering and the Objectives of the Atomic Energy Commission," "Some Economic Aspects of Atomic Power," "The Atomic Energy Commission Reactor Program," and "The Contributions of Engineering to Nuclear Energy Development."

Orders should be addressed to the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. The publication sells for $1.40.

IND. WASTE CONFERENCE AT PURDUE IN MAY

The Seventh Purdue Industrial Waste Conference will be held in the Purdue Memorial Union, Lafayette, Ind., May 7-9, 1952. Approximately 50 papers will be presented on subjects dealing with industrial wastes and their treatment.

Registration fee will not exceed $10, and hotel reservations can be made at the Purdue Union Club, Fowler Hotel, Cedar Crest Hotel and Morris Bryant Hotel.

MERCK PLANS GEORGIA PLANT

Merck & Co., Inc., is completing acquisition of a plant site on the Flint River near Albany, Ga., where the company will produce medicinal chemicals, it was announced recently. It will be the second Merck plant to be established in the South, the other being the company's Stonewall Plant at Elkton, Va. It is anticipated that the plant will begin production by the end of the year. The plant site consists of approximately 640 acres.

DOMESTIC SHEET-MICA

Freedom from dependence on foreign sources of mica is now a possibility owing to a new development of the chemical division of the General Electric Co. Domestic sources of mica may be used to produce continuous sheets of mica for electrical insulation purposes, through a special process by which mica flakes are held together. The resulting product is in the form of a continuous sheet ranging from two to six thousandths of an inch thick and possessing better dielectric strength than machine- or hand-laid mica. Referred to as micamat, the material will be in full production early in 1952. Above a sheet of the new mica product emerges from the treating machine.

NEW REFINERY FOR STANOLIND

Standard Oil Company (Indiana) intends to build a new refinery with a capacity of 15,000 barrels a day at the Williston Basin in North Dakota, A. W. Peake, president, announced last month. The refinery will be designed so that it can be expanded to run at least 30,000 barrels a day as crude production and market demand for products increased, the official said.

"A definite site will be selected soon," Mr. Peake added. "Necessary government approvals for the project will be requested in the near future. Engineering work has already been started but construction probably cannot begin until 1953."

Three Standard Oil subsidiaries already are active in the Williston Basin. Stanolind Oil and Gas Company holds oil production leases on over 4 million acres in the area. Service Pipe Line Company last year built North Dakota's first gathering system and is moving crude through it. Stanolind Oil Purchasing Company is active in buying crude in the area.

C.C.D.A. TO MEET IN NEW YORK THIS MONTH

New York City will play host, March 20, to the Commercial Chemical Development Association, which will meet at the Hotel Statler for its annual open meeting.

Theme of the meeting will be the reduction of time necessary between the discovery of a chemical material and its appearance on the chemical market. Two panels will be held—the morning session will be under the chairmanship of D. B. Keyes, consultant of New York, and will cover specifically "What can you do with organized chemical development," and the afternoon panel will have as moderator W. H. Bowman, vice-president of the Jefferson Chemical Co., and will have as its topic "What is being done with organized chemical development."

J. P. Coe, vice-president and general manager, Naugatuck Chemical Division, U. S. Rubber Co., will receive the association's annual Honor Award at a banquet that evening.

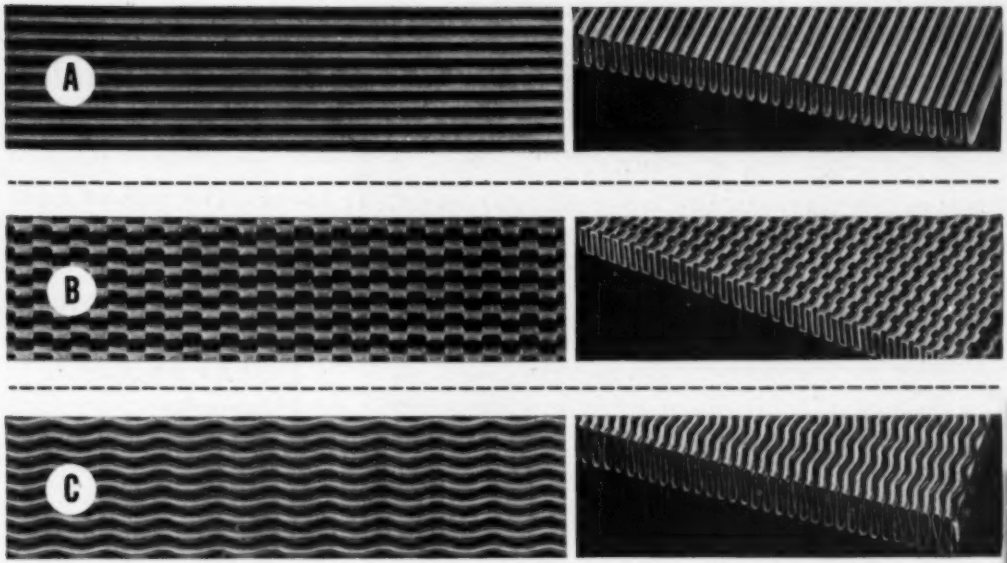
A. D. LITTLE SETTLES CLAIM AGAINST U. S.

Arthur D. Little, Inc., Cambridge, announced that it has settled its $1,500,000 claim against the United States Government for unauthorized use of certain of its vapor compression distillation patents. The patents involved cover equipment primarily employed in ships, overseas shore stations, and field units for manufacturing potable water from sea, or polluted water, sources, and were granted in the course of development work carried out by Arthur D. Little, Inc. on mobile compression distillation units used by American forces in the Pacific area during the last war.

The settlement of the claim saw the Government liability for infringement prior to the filing of the complaint in the Court of Claims released and the complaint dismissed, in consideration of payment on behalf of the Government by contractors who had made the apparatus charged to infringe. For a lump sum paid by the Government directly, Little granted the Government an irrevocable royalty-free license for the life of the patents.

BECKMAN PLANS NEW CENTER IN CALIFORNIA

Beckman Instruments, Inc., The Helipot Corp. and Arnold O. Beckman, Inc., have purchased 40 acres in the Fullerton-La Habra area in California upon which will be built facilities for development and manufacture of instruments and electronic equipment.



Three of the many types of fin section available.

TRANE Brazed Aluminum Heat Exchangers Offer Wide Choice of Heat Transfer Surfaces for Greater Design Flexibility

With Trane Brazed Aluminum Heat Exchangers, you choose from a great variety of surfaces in solving exactly your heat transfer problems. They may be straight and continuous (A). They may be serrated (B). Or they can be of herringbone design (C). With these basic designs, exactly the right surface can be selected to provide the correct ratio of heat transfer to pressure drop characteristics.

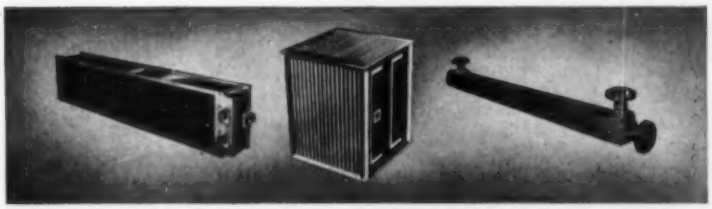
Many further variations of these general types are practical. The height and the thickness of the fin can be varied. So can the number of fins per inch. In fact, fins with entirely different patterns, heights and number of corrugations per inch can be used side-by-side to handle different fluids in the same exchanger.

Thanks to this great flexibility you can provide just the heat transfer, just the pressure drop volume, velocity number and direction of passes you want with Trane Brazed Aluminum Heat Exchangers.

Design flexibility is but one of the many advantages of Trane Brazed Aluminum Heat Exchangers. Compared to conventional exchangers, they produce more heat transfer efficiency in ¼ the space with ⅓ the weight at approximately ½ the cost.

These all-aluminum heat exchangers are rugged, too. They take test pressures up to 1,000 pounds per square inch and temperatures from −300° to 500° F.

Whether the job calls for high or low temperatures or pressures, one stream or many, Trane Brazed Aluminum Heat Exchangers can be the answer. Contact your Trane sales office or write direct.



Here are a few of the many varieties of Trane Brazed Aluminum Heat Exchangers which are now in actual service: 1) A cross flow unit for liquid-to-gas exchange used for condensing purposes. 2) A cross flow gas-to-gas unit which is used for intercooling for aircraft engines. 3) A counter flow liquid-to-liquid exchanger for high pressure application.

TRANE

MANUFACTURING ENGINEERS OF HEATING, VENTILATING AND AIR CONDITIONING EQUIPMENT

THE TRANE COMPANY, LA CROSSE, WIS.
Eastern Mfg. Division . . . Scranton, Pennsylvania
Trane Company of Canada, Ltd. . . . Toronto

OFFICES IN 80 U. S. AND 14 CANADIAN CITIES

MAGNABOND
MAGNETIC COUPLING

A BASIC ADVANCE IN INSTRUMENTATION
... eliminates the stuffing box

Particularly suited for flow measurement or level determinations

The patented, separation-proof MAGNABOND Magnetic Couplings are simple, safe, positive, and precise. They utilize a unique system of permanent magnets to pick up the float position of a primary element eliminating the need for stuffing boxes or packing glands.

After years of highly successful use with FLOWRATOR variable-area flow measurement meters, the MAGNABOND coupling's usefulness is being extended to LEVELIMETER liquid level measurement instruments, V/A Cell Kinetic Manometer flow units, and Mercury Manometer flow meters.

For more information about the MAGNABOND coupling, its applications and possibilities, ask for Catalog 75 describing F&P Levelimeters; Catalog 37 on Mercury Manometer Flow Meters; Catalog 42 on V/A Cell Flow Meter units; Catalog 50, describing MAGNABOND Transmission and Exhibiting and Controlling Instruments for use with FLOWRATOR Meters.

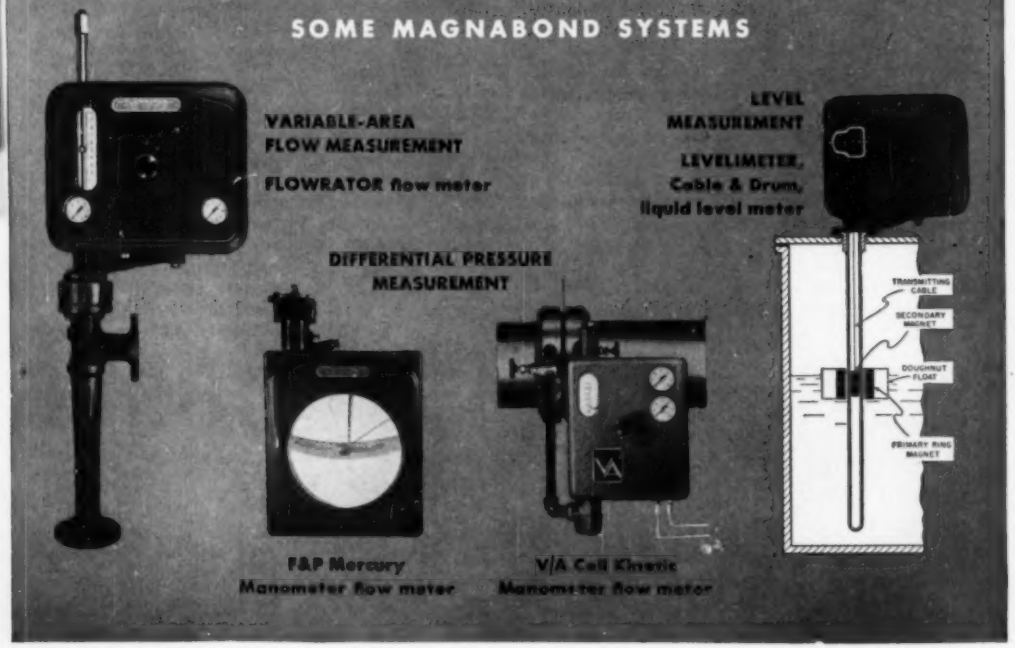
for
MOLTEN SOLIDS
INFLAMMABLES
CORROSIVES
AND OTHER
DIFFICULT FLUIDS

PROCESS
CONTROL
INSTRUMENTS

FLOWRATOR

FISCHER & PORTER COMPANY
DEPT. 2N-7H
HATBORO, PENNSYLVANIA, U.S.A.
SALES ENGINEERING OFFICES THROUGHOUT THE WORLD

SOME MAGNABOND SYSTEMS



TELEVISES MEETING OF STOCKHOLDERS

A live television program which took stockholders on a tour of company plants and mines was used by the Foote Mineral Co. at its recent stockholders' meeting for 1952. The event, the first time television has been used in such a way, was staged by the company and the Radio Corporation of America. Stockholders witnessed a pictorial tour of Foote's Exton (Pa.) plant, and by means of film, of their Kings Mountain (N.C.) plant.

The portable TV gear employed was the most extensive closed-circuit system yet installed for this type of service. Four-image orthicon field cameras were set up in strategic and widely separated locations on the 81-acre Foote property at Exton. Twelve 17-inch R.C.A. Victor receivers were placed in the cafeteria where the stockholders' meeting was held.

L. G. Bliss, Foote vice-president in charge of sales, served as master of ceremonies for the television presentation, and demonstrated company products and introduced company personnel to the assembled guests.

Stockholders saw the processing of lepidolite ores from Africa, then by means of a film, the quarrying of spodumene at Kings Mountain, Charlotte, N. C., and finally, in the plant itself, television cameras showed processing units, pilot plants, laboratories and other installations throughout the company's facilities.

POLLUTION SYMPOSIUM IN PASADENA IN MAY

The second National Air Pollution Symposium will be held May 5-6, 1952, at the Huntington Hotel, Pasadena, under the sponsorship of Stanford Research Institute, in cooperation with California Institute of Technology, University of California at Los Angeles, and University of Southern California.

A. M. Zarem, chairman of the executive committee, said that the program will cover general topics of new techniques in sampling, analysis and instrumentation, fundamental chemistry and physics of the atmosphere, the contribution of internal combustion engines and biological aspects of atmospheric contamination. Management's views on air pollution will be introduced also.

Members of the executive committee for the 1952 symposium are Dr. F. C. Lindvall of Caltech, Dean L. M. K. Boelter of U.L.A., Dean R. E. Vivian of U.S.C., and Dr. Zarem, manager of the Los Angeles division of S.R.I.

Scientists, engineers, technical workers and executives interested in phases of air pollution affecting industrial communities will be present.

You're looking at a polished section cut from a Duraspun Centrifugal Casting...a casting with 12-14% chromium. It tells better than words of the high quality of Duraspun Centrifugal Castings.

You get a fine, dense, uniform grain structure. Possible air pockets and blow holes are eliminated. Tensile strength is higher than with static castings.

Order Duraspun if you need pipe or tubing. Sizes run up to 15 feet in length; up to 32 inches OD; and down to ¼ inch wall thickness. Odd shaped pieces can be produced providing a circular hole passes uniformly down the center. These, of course, require specially designed casting forms.

If, before ordering or asking us to quote, you would like to know more about our work and facilities, send for our Catalog 3150.

THE DURALOY COMPANY

Office and Plant: Scottdale, Pa. · Eastern Office: 17 East 42nd Street, New York 17, N.Y.

Detroit Office: THE DURALOY COMPANY, 815 New Center Building

Atlanta: M. TULL Metal & Supply Co. · Chicago: P. O. NELSON, 332 S. Michigan Avenue · San Francisco: JOHN D. FENSTERMACHER, 1241 Taylor Street

Boston · Dallas · Denver · Houston · Kansas City · Los Angeles · St. Louis

EMMERICH TO GET A.I.C. MEDAL

Fred J. Emmerich, president of Allied Chemical & Dye Corp., New York, has been awarded the 1952 Gold Medal of The American Institute of Chemists.

Lawrence H. Fleet, president of the Institute, announces that the award is made in recognition of Dr. Emmerich's achievements "as a business leader devoted to building chemical industry by fostering cooperation among men skilled in chemistry, engineering, and commerce."

Presentation of the medal to Dr. Emmerich will be made at the medal award banquet which takes place at the close of the twenty-ninth annual meeting of the Institute, to be held at the Hotel Commodore, New York, May 7th and 8th.

SODIUM CHLORATE SAFETY DATA

A detailed booklet on the safe handling of sodium chlorate, has been issued by the Manufacturing Chemists' Association, Inc., describing its physical, and chemical properties. The chemical is used extensively as an oxidizing agent, in agricultural sprays and dusts and as an ingredient in certain explosives. Emphasis is placed upon the known hazards of sodium chlorate and its potentially explosive characteristics when in contact with phosphorus, sulfur, powdered metals and other substances.

Shipping regulations are discussed, the Interstate Commerce Commission having classified sodium chlorate as an oxidizing material.

In view of the extreme reactivity of sodium chlorate when in contact with oxidizable substances or organic matter, employee education and training, personal protective equipment, and first aid are covered in the discussion of precautionary measures.

The booklet may be purchased at 25¢ a copy from the M. C. A., 15th and H Streets, Washington 5, D. C.

FOOD ENGINEERING SCHOLARSHIPS BY ARMOUR

Armour and Co., Chicago meatpacking concern, has established a full tuition graduate scholarship in food engineering at Illinois Institute of Technology, Chicago, for the academic year 1952-53, W. A. Lewis, dean of the graduate school, announced last month. In addition to the scholarship, Armour has made available funds for special food engineering equipment needed to train students in this field. The scholarship will be awarded to a qualified graduate in food engineering or to a graduate in chemical engineering or chemistry.

The Work of the Leaders

"A MAN SHALL BE KNOWN BY HIS LEARNINGS"

. . . in a given division of the field of chemical engineering is presented by CHEMICAL ENGINEERING PROGRESS in the MONOGRAPH SERIES and SYMPOSIUM SERIES.

The first volume in each series has been published. If there has been a delay in receiving your copies it is because the orders have come in faster than we could get the books, and reprints of them, off the press.

ULTRASONICS

PHASE-EQUILIBRIA—Pittsburgh and Houston—second volume in the Symposium Series—should be off the press by the end of March. In it is presented the individual and collaborative work of 36 men in the field on: Methods of experimental determination; fugacity of vapor mixtures; prediction of critical properties; development of isothermal and isobaric equations; thermodynamics; conjugate liquid-phase equilibria; extractive distillation; phase-equilibria in solvent-polymer systems, in propylene oxide-water, from flash vaporization of petroleum fractions; nomographic presentation.

Price: Members, $3.75 est.; Nonmembers, $4.75 est. (approx. 150 pp. Paper covered).

REACTION KINETICS

PHASE-EQUILIBRIA

HEAT TRANSFER

DIFFUSION

MAIL THIS COUPON

FUTURES **(check here *or* yearly subscription below);** ☐ ***a second volume on phase-equilibria;*** ☐ ***a symposium on reaction kinetics;*** ☐ ***another on heat transfer;*** ☐ ***a monograph on diffusion.***

CHEMICAL ENGINEERING PROGRESS
120 E. 41st St., New York 17, N. Y.

Please send

☐ Copies of Reaction Kinetics in Chemical Engineering
☐ Copies of Ultrasonics—two symposia
Check enclosed ☐ Please bill me ☐

Name.....

Address.....

.....

.....

	PRICES *	
	Members	Nonmembers
Reaction Kinetics	$2.25	$3.00
Ultrasonics	2.00	2.75
Both Volumes	4.00	5.50

(Paper Covered)

** Add 3% City Sales Tax on deliveries within New York City limits.*

Please check:
Active Member ☐ Associate Member ☐
Junior Member ☐ Student Member ☐ Nonmember ☐

☐ Enter my subscription on a yearly basis to receive future volumes as they are issued. I will be billed as the books are published.

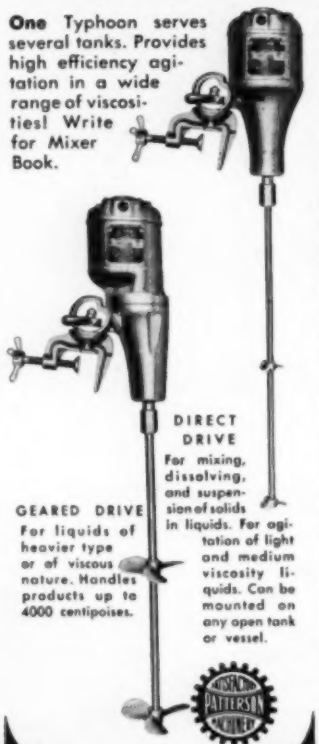
PATTERSON

TYPHOON

PORTABLE MIXERS

- POWERFUL
- EFFICIENT
- EASILY CARRIED *from batch to batch*

One Typhoon serves several tanks. Provides high efficiency agitation in a wide range of viscosities! Write for Mixer Book.

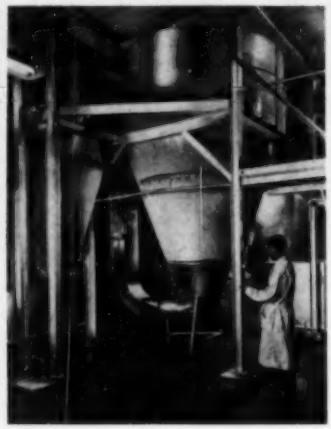


DIRECT DRIVE
For mixing, dissolving, and suspension of solids in liquids. For agitation of light and medium viscosity liquids. Can be mounted on any open tank or vessel.

GEARED DRIVE
For liquids of heavier type or of viscous nature. Handles products up to 4000 centipoises.

The Patterson Foundry and Machine Company
East Liverpool, Ohio, U. S. A.
NEW YORK BOSTON BALTIMORE PHILADELPHIA PITTSBURGH DETROIT CINCINNATI CHICAGO ST. LOUIS HOUSTON DENVER LOS ANGELES SAN FRANCISCO SEATTLE
The Patterson Foundry and Machine Company, (Canada) Limited
Toronto, Canada

NEW BOWEN TEST LAB.



Bowen Engineering, Inc., completed a new test laboratory in North Branch, N. J., recently, with equipment which included stainless steel production equipment and a laboratory spray dryer. According to the company announcement, tests can be made at temperatures up to 1000° F. in the new laboratory using direct products of combustion as the drying in medium as well as tests at lower temperatures using indirect heating.

Other operations can be tried in the test laboratory, including spray chilling, secondary heat treatment of spray-dried product, cooling of product after drying, and the classification of coarse powder from fines during the drying process.

Facilities also include a laboratory for product evaluation, refrigerator room for storage of material requiring reduced temperatures and separate powder collection room.

BEARCE RECEIVES UNIV. MAINE PULP AWARD

The University of Maine Pulp and Paper Foundation presented on Feb. 19 George D. Bearce, of Bucksport, Me., its 1952 Honor Award "in recognition of outstanding service to the pulp and paper industry in management and technology." Mr. Bearce is general manager of St. Regis Paper Co.'s operation in the State of Maine.

The presentation was made at the annual meeting of the University of Maine Pulp and Paper Alumni at a luncheon at the Biltmore Hotel. Prof. Lyle Jenness, head of the chemical engineering department at the university and member of A.I.Ch.E., was one of the speakers.

The recipient of the Foundation's first Honor Award last year was Dr. Ralph H. McKee, consulting chemical engineer, Columbia University, New York. Dr. McKee was honored for having started the first college course in pulp and paper technology in the country at the University of Maine in 1913. He is a member of A.I.Ch.E.

PACIFIC

*CORROSION RESISTANT** VALVES

150 LB. SERIES
GATE VALVE
O. S. & Y.-Bolted Bonnet
Flg'd. Ends: ½" to 8"
Scr'd. Ends: ½" to 3"
Manufactured to M.S.S. St'ds. Also Available with A.S.A. Flanges.

150 LB. SERIES
GATE VALVE
Inside Screw, Screwed Bonnet, Solid Wedge
Scr'd. Ends: ½" to 2"
Manufactured to M.S.S. St'ds.

600 LB. SERIES
GATE VALVE
O. S. & Y.-Bolted Bonnet
Flg'd. Ends: ½" to 2"
Scr'd. Ends: ½" to 2"
Manufactured to A.S.A. and A.P.I. St'ds.

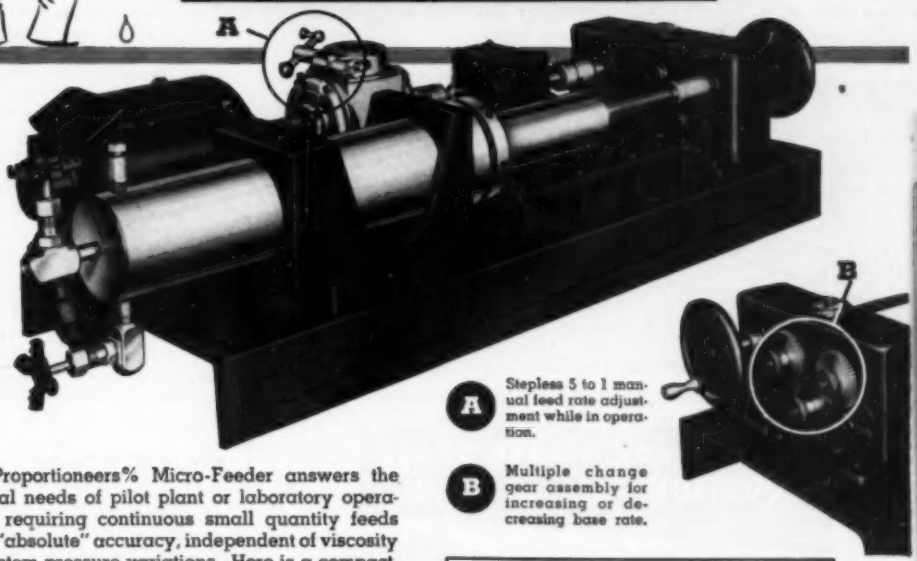
150 LB. SERIES
GLOBE VALVE
O. S. & Y.-Bolted Bonnet
Flg'd. Ends: ½" to 4"
Scr'd. Ends: ½" to 1½"
Manufactured to M.S.S. St'ds.

150 LB. SERIES
SWING CHECK
Bolted Bonnet
Flg'd. Ends: ½" to 4"
Scr'd. Ends: ½" to 1½"
Manufactured to M.S.S. St'ds.

*These Valves are regularly furnished of Type 316 or Alloy 20 Stainless Steels. Other available Corrosion Resistant Alloys, including Monel and Hastelloy can be supplied.

PACIFIC VALVES, INC.
3201 WALNUT AVE., LONG BEACH 7, CALIFORNIA
TELEPHONES: L. B. - 40-5451; Los Angeles - NEvada 6-2325
TELETYPES: L. B. - B-8076; New York City - 1-1077
Houston, Texas - HO 489

FOR MICROMETER ACCURACY IN FLUID FEEDING



A Stepless 5 to 1 manual feed rate adjustment while in operation.

B Multiple change gear assembly for increasing or decreasing base rate.

%Proportioneers% Micro-Feeder answers the special needs of pilot plant or laboratory operations requiring continuous small quantity feeds with "absolute" accuracy, independent of viscosity or system pressure variations. Here is a compact, accurate charging system or test unit which gives uniform, reproducible conditions and quick, accurate prediction of the full scale end result.

A precision ground plunger is forced into the fluid-filled cylinder at a readily adjustable, predetermined rate. Since the fluid is forced out of the cylinder by the uniform progress of the screw-driven plunger, there can be no fluid loss due to valve action or changes in plunger speed. The cylinder may be jacketed or insulated to maintain uniform conditions. The standard Micro-Feeder is available in models for feeding from 1.0 cc to 800 cc per hour and for maximum discharge pressures up to 2000 psig. Special Micro-Feeders can be furnished for other conditions. Ask for recommendations and Bulletin SM-3005-2.

Micro-Feeder Applications include . . .

1. Catalyst Testing
2. Additive Injection
3. Carburetion of Fuels
4. Explosive Mixture Analysis
5. Calibrating Instruments
6. Porosity Determination
7. Laboratory Titration
8. Injection of Vitamin Concentrates
9. Toxicity Measurements

%PROPORTIONEERS, INC.%

Write to %PROPORTIONEERS, INC.%, 419 Harris Ave., Providence 1, R. I.

Technical service representatives in principal cities of the United States, Canada, Mexico and other foreign countries.

ARTISAN DESIGNS MANUFACTURES

- Autoclaves
- Condensers
- Heat Exchangers
- Distillation Equipment
- Evaporators
- Jacketed Kettles
- Mixers
- Pipe
- Reactors
- Tanks
- *Complete Plants*

Telephone or write. Engineering Representatives throughout the United States

ARTISAN METAL PRODUCTS, INC.

Telephone: Waltham 5-6800

73 Pond Street Waltham 54, Mass.

Vacuum rectifying column—with automatic air-operated control—designed to operate either batch or continuous.

TESTING and SMALL SCALE REDUCTION *Precisely* controlled

with **AMERICAN** *Laboratory* **CRUSHERS**

For experimental laboratories, pilot plants and exacting small operations, rugged American Laboratory Crushers assure controlled, *more uniform* reduction of both fibrous and friable materials—soft or hard.

Reduce:
BY-PRODUCTS
CHEMICALS
CLAYS, COLORS
FOODS, MINERALS
and many other materials
Send us samples of your materials for test reductions. No obligation.

Custom-built with rolling ring or hammer type rotors to handle your specific reduction job with greatest possible efficiency.

Send samples to our Laboratory for testing.

Send for "BETTER TESTING and SMALL SCALE REDUCTION."

American PULVERIZER CO.

Originators and Manufacturers of Ring Crushers and Pulverizers

1215 Macklind Ave.
St. Louis 10, Mo.

CAMBRIDGE CORP. MECHANICAL DIVISION

Establishment by Cambridge Corp. of a mechanical division for the handling of a large-scale development and manufacturing program in the extreme low temperature field, was announced by Cloud Wampler, president of Carrier Corp., Syracuse, N. Y., and Earl P. Stevenson, president of Arthur D. Little, Inc., Cambridge, Mass. The two companies are joint owners of Cambridge Corp., which was formed last year to combine the commercial, manufacturing, research and technical experience of the parent organizations.

Manufacturing facilities and headquarters of the new division of Cambridge Corp. are located in Somerville, Mass. Bruce S. Old, vice-president of Arthur D. Little, Inc., has been named president of Cambridge Corp.

DAVISON CONSTRUCTING LOUISIANA PLANT

Construction was begun Feb. 12 for the plant which The Davison Chemical Corp. will build ten miles south of Lake Charles, Louisiana. To cost more than $7,000,000, the plant will produce catalyst for the petroleum-cracking refineries of the Gulf Coast area, plus other chemicals. It will employ about 200 when it goes into production, for which a target date of early next year has been set. The plant area is 18 acres.

HOOKER HEADS GAS ASSOCIATION

R. Wolcott Hooker, vice president in charge of sales of the Hooker Electrochemical Company, was elected president of the Compressed Gas Association, Inc., succeeding Daniel Mapes, vice president of Walter Kidde & Co. Mr. Hooker also was reelected president of The Chlorine Institute, Inc. on January 23 for the fourth successive year.

Other officers of the Compressed Gas Association include John H. Mills, director of priorities of the Bridgeport Brass Company, who was elected first vice president, and R. J. Thompson, manager of the Kinetic Chemicals Division of E. I. duPont de Nemours & Co., who became second vice president. Franklin R. Fetherston was reelected secretary and treasurer.

FARRELL RESIGNS FROM ATOMIC ENERGY

Major General Thomas F. Farrell, assistant general manager of the U. S. Atomic Energy Commission since August, 1951, has resigned to become managing director of ARO, Inc., which manages and operates the Arnold Engineering Development Center at Tullahoma, Tenn.

LOCAL SECTION

AKRON

Corrosion Symposium

Corrosion will be the topic of a symposium sponsored by six local sections of the American Institute of Chemical Engineers on April 21 at the Mayflower Hotel, Akron, Ohio. Participating local sections are Akron, Cleveland, Pittsburgh, Central Ohio, Ohio Valley, and Toledo. Robert C. Stell of Goodyear Tire & Rubber Co., and Walter M. Otto of Firestone Tire & Rubber Co., are co-chairmen of the symposium.

J. E. Trainer, vice-president in charge of production, Firestone Tire and Rubber Co., will be the luncheon speaker.

Following registration beginning at 8:30 A.M., a series of six papers will be presented as follows:

Keynote Address—James A. Lee, Southwestern editor, Chemical Engineering

Studies of Corrosion Reactions—R. M. Burns, chemical director, Bell Telephone Labs.

New Commercial Metals and Alloys for Corrosion Resistance—Mars Fontana, chairman, department of metallurgy, Ohio State University.

Design of Equipment from the Standpoint of Corrosion Resistance—W. Z. Friend, International Nickel Co.

Corrosion of Ferrous Metals—R. B. Hoxeng, research associate, head, chemical metallurgy division in charge of corrosion work, research and development laboratory, U. S. Steel Co.

Cathodic Protection—Speaker from Dow Chemical Co.

Registration fees are as follows:

A.I.Ch.E. Members	$2.00
Non-Members	3.00
Students	1.00

Committee members in addition to the chairmen of the symposium are the following: J. W. Kosko, Goodyear Tire and Rubber Co. (ex officio); R. A. Troupe, Goodyear Synthetic, publicity; L. A. Harris, Columbia-Southern, finances; H. H. Baker, F. V. White Industrial Sales, registration; P. G. McDermott, Maurice A. Knight Co., meeting arrangements; E. S. Mairs, B. B. Rogers Industrial Sales, printing and mailing.

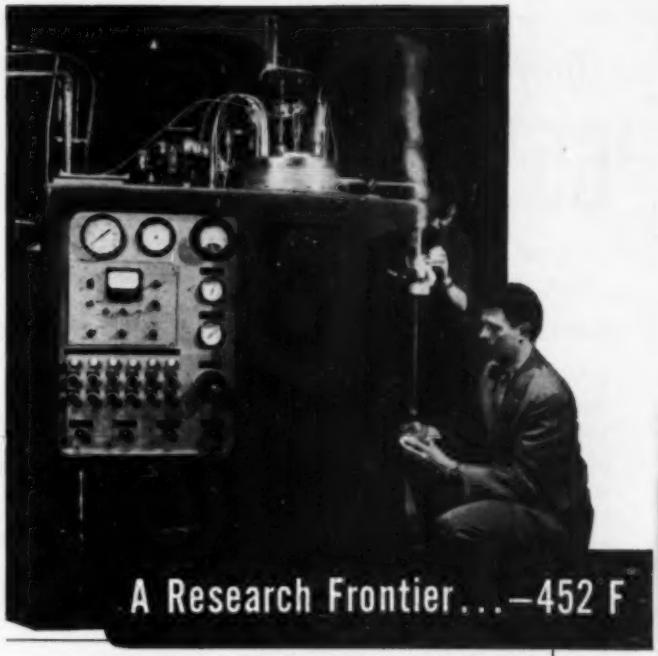
Reported by J. W. Kosko, R. A. Troupe

MARYLAND

This Section conducted a dinner meeting Jan. 15. After the business session, the members heard a talk by Theodore F. Hatch, professor of Health Engineering, University of Pittsburgh, on "Hygienic Considerations in The Design of Process Equipment." Mr. Hatch presented some thoughts on "Human Engineering."

Reported by L. C. Palmer

(*More Local Section on page* 42)



THE BASIC TOOL OF LOW-TEMPERATURE RESEARCH IS THE ADL COLLINS HELIUM CRYOSTAT. IT PROVIDES 4 LITERS OF LIQUID HELIUM PER HOUR AND MAINTAINS A TEST CHAMBER TEMPERATURE FROM AMBIENT TO –271° C.

*Boiling point of helium.

IN THEORY:

Atoms and electrons are in a state of more perfect order at extremely low temperatures. One can then study more precisely and effectively a number of variations in behavior which may at higher temperatures be masked by thermal motion.

SUPPOSE THAT:

Industrial research laboratories apply extreme low-temperature phenomena to your industry. Today, superconductors, chemical kinetics, heat capacities, property studies, are research projects . . . tomorrow, look for advances in instrumentation, metals of extraordinary hardness, accurate previews of chemical reactions. The rapid growth of this new research frontier may well affect your industry . . . how, when, or where is up to the research scientist, who, by using liquid helium, can more effectively and precisely study this new world near absolute zero.

Send for Cryostat Folder CEP-1 and booklet on Low-Temperature Physics.

ARTHUR D. LITTLE, Inc.
Mechanical Division
30 MEMORIAL DRIVE • CAMBRIDGE, MASS.

ADL Mechanical Division

Only
$65.00
½ HP
MIXER

WHIRLPOOL MIXERS
GENERAL ELECTRIC

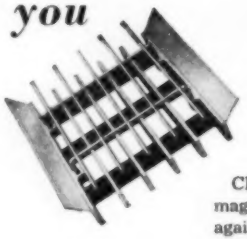
HIGH QUALITY . . . HEAVY DUTY

A heavy duty mixer . . . excellent for mixing thin liquids or large quantities. Equipped with ½ h.p. General Electric, 60 cycle, single phase, A.C., ball-bearing motor, with heavy rubber cord and molded plug; 48" stainless steel shaft; 3 stainless steel propellers, 4", deep pitch; heavy base and clamp, notch locking at many angles.

STANDARD ELECTRIC
MANUFACTURING CO., INC.
WEST BERLIN 18, NEW JERSEY

WRITE FOR CATALOG ON COMPLETE LINE OF WHIRLPOOL MIXERS

you can't drop a nail through this grate



Climb up high and drop a steel nail on this magnetic grate. Or throw nail as hard as you can against it. The nail simply can't get through.

It's obvious that the nail or other iron or steel piece will first strike a grid wire or a grate bar. That will check the momentum. Then the object will be caught with a strong magnetic grip.

The Bauer Magnetic Grate is laid on a frame in a hopper throat or floor opening to catch all steel and iron inclusions in flowable materials—grain, nuts, seeds, fruits, coffee, tea, spices, sand, clay, lime, chemicals. The grates work well in liquids, too.

Ask for Bulletin M-3-A which fully describes the magnetic grate and other Bauer Magnetic Separators.

THE BAUER BROS. CO.

1794 Sheridan Ave. • Springfield, Ohio

PHILADELPHIA-WILMINGTON

The fourth meeting of the 1951-52 season was held at Kugler's Restaurant, Philadelphia, Pa., Feb. 12, 1952. About 80 persons attended the dinner while 100 people were present for the meeting that followed.

The speaker for the evening was Douglas Courtney, program director, Institute for Research in Human Relations, Philadelphia, Pa. Dr. Courtney's talk dealt with some of the work carried out at the Institute on the quantitative evaluation of the various factors involved in leadership.

Reported by W. E. Osborn

TWIN CITY

The first meeting of 1952 took place Jan. 16, at the Angus Hotel in St. Paul. There were 49 members and guests present.

Charles Hann, Minnesota Mining Manufacturing Co. discussed "Heat Pumps" and stating that of the 750 installations around the country only two are in Minnesota, the rest are mostly in the South and West.

The major talk was given by Walter Carlson, assistant general manager, special commodities division of General Mills. His subject was, "Vitamin D Production, A Typical Growth Cycle of a Chemical Process." He discussed the historical development of Vitamin D. General Hills has played an important part in this, he claimed, as it was one of the first to produce Vitamin D economically through the action of ultraviolet light on ergosterol.

Reported by R. H. Fredrickson

NEW ORLEANS

This Section held a dinner meeting at the "Little House" Restaurant Feb. 5, 1952. "Coca-Cola—A Romantic Industry in Romantic New Orleans" was the subject of a talk by Arthur E. Christen, plant superintendent of the Louisiana Coca Cola Bottling Co. A group of 28 people heard the history of Coca Cola and the logistics of the largest single Coca Cola bottling plant in the world located in New Orleans.

Officers for the year are as follows:

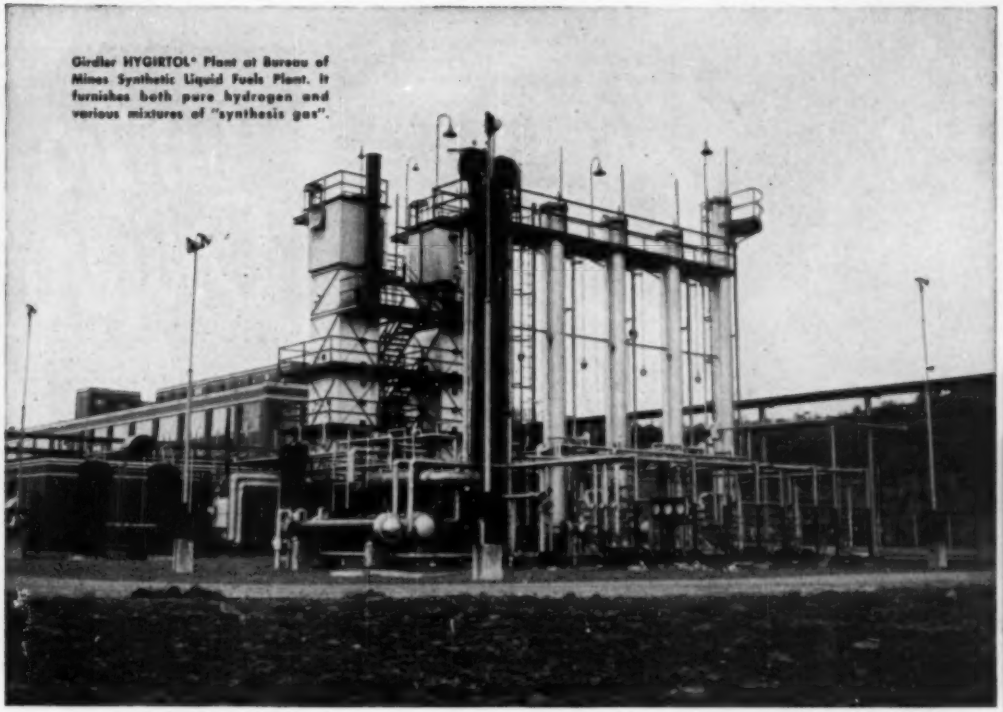
Chairman.....Leon Godchaux, II
Vice-Chairman.....Henri J. Molaison
Sec'y-Treas......Kenneth M. Decossas

Other executive committeemen are:

William N. Tuller, Frances M. Taylor, Carl M. Peters, E. F. Pollard

Reported by Joseph Pominski

(*More Local Section on page* 44)



Girdler HYGIRTOL* Plant at Bureau of Mines Synthetic Liquid Fuels Plant. It furnishes both pure hydrogen and various mixtures of "synthesis gas".

Girdler gas plant speeds synthetic fuels process development

ENGINEERS of the U. S. Bureau of Mines believe that the development of processes to produce synthetic liquid fuels will provide a potent wartime ace-in-the-hole.

At the Bureau's plant near Pittsburgh, pilot operations are bringing such processes closer to perfection. Here a Girdler HYGIRTOL* Plant first converts natural gas into hydrogen and "synthesis gas"—a mixture of hydrogen and carbon monoxide. Experiments seek to develop the best process for subsequent conversion of the synthesis gas to liquid hydrocarbons.

In a pilot plant operation such as this, operators must be able to change conditions and gas mixtures frequently. With the HYGIRTOL Plant mixed gas ratios can be varied over a wide range—from 1:1 to 4:1. Although large quantities of gas are produced, mixture ratios can be maintained within 0.2 per cent.

Such control and flexibility simplify experimentation and speed up results. If efficient gas processing is necessary in your operations, let us help you too. The Girdler Corporation, Gas Processes Div., Louisville 1, Kentucky.

WRITE FOR FREE BOOKLET

It describes Girdler services in designing and building plants to produce, purify or use chemical process gases and plants to purify liquid or gaseous hydrocarbons.

*HYGIRTOL is a trade mark of The Girdler Corporation

the GIRDLER Corporation

Gas Processes Division

Now... FEON
SYNTHETIC FABRICS
for DUST COLLECTORS

For Any Type of Equipment

New FEON fabrics, specially woven of Nylon, Dupont Orlon®, or Dynel for dry separation of corrosive and hot materials, now make possible tremendous savings. Under severe conditions, FEON synthetics last ten to thirty times longer than ordinary filter fabrics. One user reports over $15,000 saved in one year!

Choice of many weaves—fabricated by FEON for any collector—gives maximum efficiency for a wide range of gases and particle sizes . . . permits handling practically all chemicals . . . at temperatures up to 300 deg. F

For free samples and specific recommendations, send us the facts on your job today.

41-A

New FEON SELECTOR CHART — Containing Samples, Technical Data, Case Histories.

FILTRATION FABRICS DIVISION
FILTRATION ENGINEERS, INC.
155 Oraton St., Newark 4, N. J.

PITTSBURGH

"Ethylene Petrochemicals—Today and Tomorrow" was the topic of an illustrated talk by J. W. Hutcheson, Beacon (N.Y.) Research Laboratories, The Texas Co., at a dinner meeting of this Section held Feb. 6 at the College Club at Pittsburgh. Mr. Hutcheson described the pace-setting and continuing expansion of the American petrochemicals industry, with particular emphasis on the field of ethylene derivatives. The chemistry of the impressive list of chemicals and intermediates produced from ethylene was reviewed in order to show the importance of ethylene to the chemical industries. A comparison was made between the petrochemical and petroleum industries, with regard to a number of factors, including investment and utility requirements, marketing considerations, and research-technical requirements.

Reported by Hugh L. Kellner

OKLAHOMA

The following were elected officers for 1952:

Chairman.....G. E. Hays
Vice-Chairman.....H. B. Irwin
Secretary.....G. H. Dale
Treasurer.....J. W. Davison
Executive Committee: L. W. Pollock
D. H. White

The six men listed above constitute the Executive Committee of this Section and all are associated with the Phillips Petroleum Co.

Reported by G. H. Dale

CENTRAL OHIO

The newly elected officers for 1952 are as follows:

Chairman—John Clegg, Battelle Institute, Columbus.
Vice-Chairman — C. J. Geankoplis, Chem. Eng. Dept., Ohio State University, Columbus.
Sec'y-Treas.—Keith Jacobs, Ironsides Co., Columbus.
Executive Committee—Jack Grant, Fiberglas Corp., Newark, Ohio.
Ralph Vogel, National Lime and Stone Co., Carey, Ohio.
E. A. Beidler, Battelle Institute, Columbus.

Reported by C. J. Geankoplis

BATON ROUGE

At the meeting on Jan. 28, 1952, E. R. Gilliland, acting head of the chemical engineering department and associate director of the Laboratory for Nuclear Science and Engineering at M.I.T. addressed 71 people on "Gas Mixing in Beds of Fluidized Solids."

In his talk, Dr. Gilliland developed the conclusions that back-mixing of the

(*Continued on page* 45)

INVESTIGATE THE
Turbo-Dryer®
. . . gentle handling in drying — through repeated piling and spreading.
. . . repeat orders from nationally known concerns testify to its merits.
for
GRANULES • BEADS • POWDERS • CRYSTALS
PASTES • SLUDGES • SLURRIES
Agents in Principal Cities
WYSSMONT COMPANY
37-04E Northern Boulevard
Long Island City 1, N. Y.

SPECIALISTS IN ALL
RESISTANT PIPING MATERIALS
TO YOUR SPECIFICATIONS
P.M. RESISTANT MATERIALS
• PIPE
• VALVES
• FITTINGS
• FASTENINGS
STAINLESS • ALUMINUM
SARAN • HARD RUBBER
POLYETHYLENE • TYGON
USCOLITE • EVERDUR
FULL RANGE OF SIZES
Complete Stocks—Prompt Shipment
(Reference No. CEP 352)
RAY MILLER
254 NORTH 10th STREET, NEWARK 7, N. J.
1210 HAYS STREET, HOUSTON, TEXAS
6240 KANAWHA TPK., SO. CHARLESTON, W. VA.

gas does occur, but is less important than residence time. From the experiments at M.I.T. it was learned that, in effect, part of the gas is by-passed through the bed in a "bubble" of gas and dispersed phase solids. This non-uniform flow can reduce materially the effectiveness of contact between the gas and solids; therefore to obtain the same effect as with uniform flow, a proportionately larger reaction volume would be needed.

A guest of the section was W. E. Catterall, of the A.I.Ch.E. Research Committee who kindly reported on the aims and activities of that committee. Dr. Catterall indicated that the project for determining the efficiency of bubble-plate columns was now well mapped and industrial sponsors are being sought to finance different phases of the work at three qualified universities.

Reported by Richard H. Bretz

DETROIT

A joint meeting between the A.I.Ch.E. and Engineering Society of Detroit was held Feb. 13. William H. Williams, Dow Chemical Co., addressed the group of 125 on "Housing for Chemical Manufacturing Operations." Outdoor constructions, its problems and economic considerations were emphasized. The major address was preceded by a dinner with an address by H. D. Brown, director, Detroit Historical Museum.

Reported by Dwight Miller

OHIO VALLEY

This Section had a dinner meeting Feb. 4 at the Cincinnati Engineering Society Building. Following the dinner W. H. Williamson from the American Wheelobrator and Equipment Corp. gave a talk on "Chemical Plant Hazards and Safety Standards." He discussed in particular the hazards encountered in chemical industries.

The April meeting, scheduled for April 16, will be a joint meeting with the American Society for Quality Control.

Reported by N. W. Morley

BOSTON ICHTHYOLOGISTS

Economic aspects of chemical engineering projects will be the subject of the second annual technical symposium to be held April 16 by this Section, Gordon Kiddoo, committee chairman, announced.

Five technical papers on project preparation and a panel discussion by management representatives of process industries are scheduled for the afternoon program. The symposium will be

(*Continued on page* 51)

Lawrence 2-Stage Vertical Pump for Pumping Liquid Chlorine out of Tanks.

PUMPS to handle LIQUID CHLORINE

Pumping liquid chlorine calls for more ingenuity and engineering skill than is available from the average pump manufacturer. Formerly it was pumped pneumatically. This method was attended by considerable loss of chlorine due to contamination through contact with air. In addition, chlorine vapors in the presence of even a small amount of moisture in the air are very corrosive and destructive to equipment.

To overcome this, Lawrence engineers in collaboration with manufacturers of chlorine, developed a pump with a special packing box which prevents any contamination of the chlorine or corrosion of any of the equipment and also prevents the escape of the chlorine fumes to the atmosphere.

For over 80 years Lawrence has been making pumps to handle every acid or chemical fluid used in industry. If you have a particularly difficult chemical pumping problem, we can save you both time and money. Write us the pertinent details, no obligation.

Send for Bulletin 203-5 for a complete summary of acid and chemical pump data.

LAWRENCE PUMPS

LAWRENCE
MACHINE & PUMP CORPORATION
375 MARKET STREET, LAWRENCE, MASS.

In the laboratory — in the plant — BECKMAN pH CONTROL can be used in many valuable ways!

THE BECKMAN MODEL H-2 pH METER is one of a complete range of Beckman pH Meters available for every type of application*. The H-2 is particularly recommended for applications where high accuracy and simple operation—combined with the convenience and low cost of 115-v. AC operation—are desired.

It provides instant and direct pH readings, and a simple, built-in dial permits quick, convenient temperature compensation over the entire range of 0° to 100°C (32° to 212° F.). High reading accuracy is assured by wide-spread dual range scale that reads from 0 to 8 pH or from 6 to 14 pH at the turn of a switch. Same switch also provides instant millivolt readings from 0 to ±800 mv and from ±600 to ±1400 mv for titrations and oxidation-reduction measurements.

Built-in electrode support and compact case design save valuable space and permit easy portability to various plant locations.

Particularly important is the wide range of factory-sealed, maintenance-free Beckman Glass Electrodes available for use with this instrument . . . electrodes that are virtually unbreakable . . . that cover extreme temperature ranges from below freezing to above boiling . . . that have an unprecedented pH range with negligible errors . . . that are abrasion-resistant and chemically durable to a degree never before thought possible in glass electrodes.

*In addition to the H-2 Meter, other Beckman pH equipment includes completely automatic pH indication and control instruments for large-scale process applications . . . battery-operated models for complete portability in plant and field use . . . and a laboratory type instrument that features maximum versatility and accuracy for research and laboratory applications

In virtually all types of chemical laboratories—both in industry and science—Beckman pH instruments are playing an increasingly important role in simplifying operations, reducing processing costs, increasing uniformity and quality of the finished product.

Most laboratories are already familiar with the unique advantages of Beckman electrometric methods in making pH measurements . . . the far greater accuracy, speed and simplicity of making pH determinations without human errors in color judgment and free from the other inaccuracies and inconveniences of colorimetric methods. But many laboratories are not fully aware of the other useful ways Beckman pH Meters can be used in modern laboratory and industrial chemistry.

For example, Beckman pH instruments can also be used to obtain greater accuracy and convenience in various types of titrations and end-point determinations . . . they can be used for making a wide range of millivolt readings . . . and a varied selection of special-purpose Beckman electrodes permits many other types of electrochemical measurements to be made, quickly and accurately.

In fact, the great variety of Beckman Glass Electrodes—the most rugged, most advanced and most diversified in the industry—permits the utmost versatility in the application of Beckman pH Meters. These electrodes cover the complete temperature range from below freezing to above boiling, can be used at even high pH values with negligible sodium errors, are factory sealed (require no maintenance) and are unusually resistant to alkalis, acids and rough treatment.

Among the many Beckman pH Meters available, the Model H-2 Meter illustrated above is most popular for general use. A few of its many unique features are outlined at left. For further details on this and other Beckman instruments see your authorized Beckman dealer, or write direct.

BECKMAN INSTRUMENTS, INC.
South Pasadena 35, Calif.
Factory Service Branches:
NEW YORK • CHICAGO • LOS ANGELES

Send for free booklet "What Every Executive Should Know About pH." It's helpful and informative.

BECKMAN INSTRUMENTS
control modern industries

Beckman Instruments: pH Meters and Electrodes — Spectrophotometers — Radioactivity Meters — Special Instruments

Chemical Engineering Progress

DATA SERVICE

EQUIPMENT

1 • TEFLON PACKING. A teflon-impregnated braided, asbestos packing of moderate price for resistance against acids, alkalis and solvents, is new with Flexrock Co. Serviceable from −100° F. to 500° F., furnished in continuous lengths in sizes from ⅛ in. to 1 in.

2 • CARTESIAN MONOSTAT. A monostat for automatic vacuum and pressure control in laboratory and pilot plant, from the Emil Greiner Co. Automatic, once vacuum has been set system may be shut down without disturbing the setting.

3 • PORTABLE MIXER. Process Industries Engineers, Inc., new portable mixer. Separate motor coupled to propeller shaft by flexible drive. Motor not at top end of propeller shaft; coupled by drive shaft of any length. Mixer has lever-operated positioning device.

4 • TRACTO-LIFT. Fork track combining outside adaptability of tractor with lifting power of forked truck. Tracto-Lift Co. Heavy duty industrial tractor with four sizes of lifts. Capacities from 3000 to 6000 lbs. Fork lengths 30 in. to 60 in., lifting heights to 12 ft., 6 in. For outside handling problems.

5 • LINE PURIFIER. V. D. Anderson Co. low cost purifier for ½ in. to 2 in. pipe lines. For steam-processing lines. Centrifugal element throws solids and water outward to the purifier walls. For kettles, sterilizers, vulcanizing machines, protection of small engines and turbines from rust and other solids, purification of vapor from evaporation or distillation units, etc. For steam applications up to 400 lbs./sq.in. gage and 500° F.

6 • ULTRA-VIOLET LAMP. A long wave portable ultraviolet lamp for applying principles of fluorescence to inspection, laboratory analysis, and display techniques, is announced by Ultra-Violet Products, Inc., 3660 A. Six different models.

7 • BY-PASS STEAM TRAP. By-pass steam trap for processing industries where continuous operation is essential. Velan Engineering Co. Signals which of two valves is closed. Integral unit allows the steam trap to be serviced in the line under full steam pressure, parts replaced, repacking or blowing out of condensate lines with steam without interrupting steam feed to processing unit.

8 • FILLING SCALE. For bagging bulk chemicals, plastics, etc., Thayer Scale & Engineering Corp. new filling scale which weighs to $\frac{1}{10}$ lb. accuracy. Automatic. Speeds up to 12 a min. for 50 lb. bags and 10 a min. for 100 lb. bags. Self-gripping bag holder, shock-proof leverage scale. Feeding system uses both gravity and vibration.

9 • SIGHT FLOW INDICATORS. A full line of sight flow indicators by Jacoby-Tarbox Corp. Available in sizes from ¼ in. through 6 in. in various types. Large variety of metals with Pyrex sight glasses and neoprene gaskets.

10 • WHIRLPOOL MIXER. A low-cost mixer from Standard Electric Mfg. Co., Inc., with ⅓ hp. motor and stainless steel shaft and two balanced polished stainless 4-in. propellers. Stock item for ready delivery. Explosion-proof motor, clamp locks propeller in different positions. Mountable on tank.

11 • CERAMIC FITTING. Robinson Clay Product Co. has developed a new joint for industrial clay pipe which combines a male-threaded polyvinyl chloride fitting on the end of clay pipe with a phenolic plastic collar. The fittings, trade named Screw-Seal, are resistant to acids, hydrocarbons, reducing atmospheres, etc. The new pipe-and-joint combination is available in 4-, 6-, and 8-in. internal diameters with standard fittings. Plastic is cast directly on the pipe with the outer surface molded to a tapered thread. The company also makes a pressure-molded union in the form of a split flange bolted together at the side for places difficult to service.

12 • ARMORED HYDRAULIC CABLE. For pneumatic and hydraulic control circuits, Bailey Meter Co. has a new armored cable. It is a flexible transmission line encasing several ¼ in. O.D. aluminum or copper tubes. The hydraulic tubes are wrapped in water-repellent insulating cement, and encased in the armor a heavy galvanized strip similar to that of BX electric cable. Available

Mail Card for more data ➡

Cards valid for only six months after date of issue

Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1	2	3	4	5	6	7	8	9	10	11	12	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
47	48	49	50	51	52	53	54	55	56	57	58	59	60	

PLEASE TYPE OR PRINT

Name _____ Position _____

Company _____

Address _____

City _____ Zone _____ State _____

March 1952

Chemical Engineering Progress

DATA SERVICE

in bundles of 4, 8 and 12 tubes the cable is capable of transmitting hydraulic control pressures as high as 3000 lbs./sq.in.gage. Connections, take-offs may be made in standard electrical junction boxes. Support racks are eliminated and tracer tubes identify corresponding tube ends between cable connecting points.

14 • DIAL THERMOMETERS. Rochester Mfg. Co. has perfected a new process for welding thin sections of stainless steel. In production on their dial-type bimetallic thermometers, the stainless steel construction gives added corrosion resistance over the previous silver-soldered units. New thermometer has a special recalibration device.

15 • DRUM STORAGE RACK. A drum storage rack which permits removal of drums by fork truck. Horizontal storage position makes it possible for faucets to be attached to the drums for drawing-off small quantities. Equipment Manufacturing, Inc. Of welded square tubular steel, rack permits stacking of drums to ceiling heights. Initial racks are engineered for 55-gal. drums and rack is of knock-down, portable type.

16 • POLYETHYLENE EXHAUST SYSTEMS. For drawing off corrosive vapors and fumes American Agile Corp. has designed an exhaust system fabricated from polyethylene. Offers corrosion resistance against most acid fumes. For use between −200° F. and 170° F., on processing tanks, exhaust hoods, fume ducts, etc.

17 • BALLOMATIC BACKSTOP. For use in vertical turbine water pumps to prevent damaging backspins, U. S. Electrical Motors, Inc., has designed a new stop. Principle involves the use of hardened steel balls in an outer rotating member which, after power is off and motor stops turning, drop back and lock the rotating member to a stationary ratchet. Allows only 1/63 back-revolution before rotor is locked.

18 • VISUAL FLOW LINE INDICATOR. A flow indicator for incorporation into line. Consists of a brass housing in which is inserted a transparent high pressure Pyrex tube with a ceramic eye. Allin Mfg. Co. Available in copper tube sizes of 1/4, 3/8, 1/2 and 5/8-in. diam. for oil pressure lines, refrigerant, chemical lines, etc.

19 • HIGH CAPACITY MIXERS. Lloyd Engineering Co. with custom-made mixers for the process industries, ranging from 400 to 1200 gals. Specially designed agitators and also scrapers for cleaning material being mixed, from tank side. Built to specification.

CHEMICALS

20 • U. F. RESIN. For use as the amine component of white industrial baking enamels, a new urea-formaldehyde resin is announced by Rohm & Haas Co. Based on propyl alcohol instead of butanol, company says it will have fewer price fluctuations.

21 • N,N' METHYLENEBISACRYLAMIDE. For the first time in trial lots, N,N' methylenebisacrylamide. American Cyanamid Co. Monomer undergoes reactions typical of vinyl amide groups. For use in molding compounds, surface coatings, textile finishes, and ion-exchange resins.

22 • RESIN-ROSIN SIZING. For the paper industry a blended synthetic resin-rosing sizing described in a new booklet by the Monsanto Chemical Co. Contains data on advantages, improvements in operation, preparation of size, characteristics, etc.

23 • VINYL LATICES. A series of new vinyl resin latices by Goodyear Tire & Rubber Co. First in series is aqueous dispersion of vinyl chloride copolymer for use in the textile and paper-coating industries. Gives grease proofness, chemical resistance and moisture resistance to fabrics and papers, for use as pigment binders for inks, paints, and binders, for nonwoven fabrics and felt, and as a sizing for textiles.

24 • BRIGHT SILVER PLATE. Hanson-Van Winkle-Munning Co. has a new commercial silver-plating process which gives bright silver plate without buffing or scratch brushing. Used in conventional plating equipment. Existing solutions can be converted.

25 • 2,5-DIMETHYL PIPERAZINE. This compound, an alicyclic disecondary amine, is now available in pilot plant quantities from Carbide & Carbon

Postage Will Be Paid by Addressee

No Postage Stamp Necessary If Mailed in the United States

BUSINESS REPLY CARD

First Class Permit No. 48890, Sec. 349, P. L. & R., New York, N. Y.

Chemical Engineering Progress

120 East 41st Street

New York 17,

New York

USE THIS CARD FOR FREE DATA

Chemicals Co. Technical bulletin from the company shows potential use as an intermediate in pharmaceutical synthesis, resins, rubber antioxidants and activators, textile-finishing agents, and boiler-treating compounds. Bulletin available.

26 • *N-BUTYL DIETHANOLAMINE.* A new technical bulletin issued by Carbide & Carbon Chemicals Co. describes n-butyl diethanolamine. Gives properties, shipping data, uses, potential applications, etc. For the following industries: surface-active agent, resin, dyestuff, rubber, plasticizer, pharmaceutical and fungicide.

27 • *NEOPRENE COATINGS.* From Gates Engineering Co. a series of liquid neoprene coatings for corrosion protection. Will adhere to metal, wood, concrete with or without primer. Can be brushed, sprayed, dipped, rollered or flowed onto surface.

28 • *LOW FLOW DRIER.* A tallate-type lead drier, for paints and allied compositions; Nuolate lead 24% gives flow at 0° F. Eliminates crystallization or solidification at freezing temperatures.

29 • *PHOSPHATASE.* Sigma Chemical Co. is offering a white, crystalline *p*-Nitrophenyl phosphate for determining serum phosphatase. Available in weighed capsules of 100 mg. and up.

BULLETINS

30 • *THERMOCOUPLE GLANDS.* Conax Corp. has developed a thermocouple gland to seal bare wires entering pressure or vacuum chambers. Two wires are sealed in each unit with the seal being powdered talc. By compressing the talc to 100,000 lbs./sq.in. it becomes rigid. For use on mixers, kettles, reactors, etc. To temperatures more than 1500° F. and liquid pressures as high as 4000 lbs./sq.in.

31 • *TUBULAR GRINDING MEDIUM.* Tubular-shaped high-fired ceramic grinding media for wet and dry grinding processes. Bulletin gives physical properties, uses in mills, illustrated to show type and advantages, plus excerpts on field reports on the use of Burundum as a grinding medium. U. S. Stoneware Co.

32 • *IDENTIFICATION CHART.* For users of stainless steels, Carpenter Steel Co. has issued an identification chart for quick identification of stainless types. Useful for separating scrap and identifying mixed stocks. Describes how and when to use each of eleven different tests for identification. Covers tests with nitric acid, muriatic acid, magnet, spark, hardness, sulfur spot, nickel spot and stabilization.

33 • *BLENDING SYSTEM.* Bowser, Inc., with an extensive bulletin on new precision blending system for blending, compounding, or mixing of lube oils, beverages, coolants, chemicals, liquid foods, etc. Well illustrated with flow diagrams. Gives explanation of complete system. Blending formulas remain constant regardless of size of meters or rate of flow. Also gives wiring diagram, installation of a four-meter system, setting and controls. Can be added to with separate units.

34 • *PALLETS.* The National Pallet Corp. with a bulletin on all the types of pallets available. For engineers with a materials-handling and storage problem. Publication gives construction details, sizes, load limits, etc., of about every type of hardwood pallet for all phases of materials-handling.

35 • *VERTICAL PUMPS.* Lawrence Machine & Pump Corp. bulletin on centrifugal vertical pumps. Covers submerged, outside mounted, high vacuum, low N.P.S.H. dual-discharge and power pumps, etc., made by the company. Illustrated.

36 • *NEOPRENE-TREATED PAPER.* A bulletin from Du Pont on use of neoprene latex addition to pulp to increase wet strength, internal bond, and impact strength of paper. Physical properties and improvement in quality of paper covered.

37 • *SMALL-SCALE CRUSHERS.* For the laboratory and pilot plant, American Pulverizer Co. bulletin on crushers. Covers crushers, grinders, and shredders, rolling ring, and hammer mills. Gives sizes which include up to 10 hp., capacities from 600-2000 lbs./hr. Shows typical installations.

38 • *DOWTHERM EQUIPMENT.* Union Iron Works bulletin on Dowtherm process equipment. 250,000 to 30,000,000 B.t.u./hr. at 750° F. Units are gas or oil. Shop or field assembly. Chart in bulletin covers A- and E-type vapors, with properties of both materials given.

39 • *VIBRATOR EQUIPMENT.* A catalog from Syntron Co., specialists in vibratory equipment. Covers feeders, conveyors, elevators, weighing equipment, pile drivers, hammers of all sorts, packers and jolters, sieve testers, etc. Illustrated. Specifications given of sizes, accessories, etc.

40 • *WATER CONDITIONING.* Elgin Softener Corp. bulletin covers various methods of conditioning water and the purposes served by each. Features an improved water softener of double-check design which gives 44% greater capacity and prevents zeolite loss. Covers ion-exchange resins, degasitors, water-treating chemicals, technical and engineering facilities, deionizers, filters, purifiers.

41 • *CAM PROGRAMMER THERMOMETERS.* Minneapolis-Honeywell Brown Instruments Division catalog on a new instrument for time-temperature control. Combines as many as six functions from a standard instrument case. Particularly adapted to batch processes where specific schedule is repeated. For all temperature-control processes. Cams are made up of transparent plastics. Bulletin describes function completely,

shows cams, instruments, method of cutting cams on the job, dimensions, construction, etc.

42 • COLD FACTS. A newsletter from Arthur D. Little, Inc., compiled and edited by its mechanical division, composed of notes and current activities in the low temperature and electromagnetic research. Will be published quarterly and sent to those interested.

43 • LUMMUS. A 16-page brochure issued by the Lummus Co., titled, "Meet the Lummus Company." Explains and illustrates the functions of the company. Each branch office, affiliate, laboratory and manufacturing arm of the company described.

44 • AIR MOVER. A device for moving large volumes of air quickly in situations requiring intermittent or emergency ventilation. Mine Safety Appliance Co. Called Lamb Air-Mover, the unit is horn-shaped with a bell-formed base. Uses compressed air or steam from any supply source to move air by jet principle. Portable, three models available in weights from 6 to 47 lbs.

45 • STEEL FLOORING. Open Steel Flooring Inst., Inc., has published a 16-page idea book. Illustrated with installation photographs showing possibilities for use of steel grating. Explains types and features of steel grating, shows use in industry, gives tables and specifications for safe loads.

46 • BAG PACKER. Two models of a new bag packer—one for bagging granulated or powdered materials, the other for dry insecticides, are available from H. L. Stoker Co. Bulletin describes equipment. One unit delivers a cubic foot in 5 sec., has positive force feed in both hopper and filling nozzle. The other delivers 50 lbs. in 6 secs.

47 • CENTRIFUGAL OIL PURIFIERS. Bulletin from Sharples Corp. on purification of industrial oils. Uses high centrifugal force to remove dirt, tank scale and moisture, carbon particles, etc. Also gives method of operation, procedure of cleaning, details and specifications of models, with or without built-in electric heaters.

48 • COATING TERMS. More than 200 definitions of terms commonly used in industrial product finishing are explained in a new booklet issued by the Sherwin-Williams Co. Begins with abrasion resistance and continues through the alphabet to zinc chromate.

49 • OXYGEN DETERMINATION. An instrument bulletin from Minneapolis Honeywell, Brown Instruments Div. which describes a Beckman oxygen analyzer combined with a Brown recorder. Provides an accurate record of oxygen measurement from a few parts per million to 100% oxygen. Measures oxygen directly, based on the fact that oxygen is paramagnetic and the oxygen content of argas can be measured by its volume magnetic susceptibility.

50 • VALVE TOPICS. A publication, "Valve Topics," by the Cooper Alloy Foundry Co. for those who design, specify, use, or purchase stainless steel valves, or fittings.

51 • MATERIALS IN CONTINUOUS PRODUCTION. A reprint of a talk given by R. P. Lowe before the Akron Chapter of A.I.Ch.E. Covers adjustable stroke metering pumps, displacement meters, orifice meters, weigh tanks, and proportioning of dry materials.

52 • VENT VALVE. Black, Sivalls & Bryson, Inc., new bulletin on combination pressure-vacuum vent valves. Gives complete description on two models—one with a flame arrester element and the other without. Contains 14 relieving capacity charts one for each valve size. Operating data, specifications, and prices are also included.

53 • THERMOSWITCH. Fenwal, Inc., catalog on thermocontrols. Constructed with two silver contacts, on a curved, nickel-iron strut, and mounted under tension or compression in a seamless brass tube. Control is calibrated by an adjusting screw. Expansion or contraction causes the contacts to make or break. Bulletin covers not only the basic principle but also diagrams of reaction times, responsive areas, selection and application and extensive description of all models available.

54 • FLUID-PROCESSING EQUIPMENT. A bulletin describing the application of a wide range of equipment to processing liquids, air, and other gases from the Selas Corp. Describes eight types of equipment. Radiant heaters for batch, and continuous processing, liquid phase separators, microfilters, entrainment separators, a vape-sorber for removing petroleum vapor from air and gas lines, a dehydrator, and an indicating air-gas flow meter.

55 • DEMINERALIZER. Barnstead Still & Sterilizer Co. describes a convenient water demineralizer for laboratories. Connects directly to any water supply. Delivers demineralized water in a continuous flow of from 5 to 8 gals./hr. Includes a direct-reading meter and an indicator calibrated in specific resistance, and in parts per million. Has capacity to remove 1100 gr. of salts. Cartridge type, removable and replaceable. Prices shown.

56 • GRINDING MILLS. A comprehensive collection of engineering data on grinding mills for rock products, cement, chemical, and mining industries from Allis-Chalmers Mfg. Co. Covers all phases of grinding—rod, pebble, etc., together with data on parts, specifications, dimensions, grinding circuits, etc.

57 • CENTRIFUGAL PUMPS. An engineering bulletin from Worthington Pump & Machinery Corp. Covers all types of centrifugal pumps made for the chemical and process industries. Sectional drawings. Mechanical seals explained, as well as explanation about the alloy Worthite.

58 • HYDROCARBON DETECTOR. A portable lightweight aromatic hydrocarbon detector is described in a new bulletin from Mine Safety Appliances Co. Will determine toxic concentrations of aromatics; uses chemical detection system which changes from white to brown after exposure to hydrocarbon vapors. Separate graduations on instrument for benzene, toluene and xylene.

59 • KARBATE KATALOG. New 20-page catalog describing National Impervious carbon and graphite products of National Carbon Co. Various kinds of carbon products for chemical application, including heat exchangers, jets, pipes, fittings, valves, pumps, towers, and tower accessories, etc. Data also on performances, specifications, etc.

60 • VALVE LUBRICATION. Minneapolis-Honeywell Regulator Co. reprint on proper valve lubrication of control valves. Discusses the types of lubricants, plus chart on types of lubricants for specific surfaces.

LOCAL SECTION NEWS

(*Continued from page 45*)

followed by a preprandial hour, dinner, and an evening speaker.

The meeting will begin at two o'clock at the University Club, 40 Trinity Place, Boston. Philip Seaver of Badger Manufacturing Co., Cambridge, is in charge of reservations.

One hundred chemical engineers and guests gathered at the M.I.T. Graduate House Campus Room Jan. 25, 1952 to dine and listen to Dr. Ralph Hower of the Harvard Business School discuss "Problems in Handling Technical Personnel" from the academic and theoretical point of view. Considerable discussion was provoked by this timely but usually controversial subject.

Reported by George J. Odom and L. F. Loutrel, Jr.

TERRE HAUTE

At the Jan. 24 meeting, Prof. R. Norris Shreve addressed 50 members and affiliates on "Revolution in the Chemical Field." The growth patterns of several phases of the chemical industry were traced and extrapolations to future expectations were made.

Chairman A. C. Miller announced that the Council of the Institute had authorized formation of the Terre Haute Section. Charles E. Kircher has been elected as representative, and J. F. Dudley as alternate, to the Local Sections Committee of the Institue.

Barclay Morrison, of Carpenter Steel Co., spoke on "The Corrosion Engineers Approach to Stainless Steel" at one of the last meetings of 1951 before 68 members and guests. In times of metals shortages, it is essential that design engineers plan their layout to achieve optimum life for alloys, Mr. Morrison pointed out. A review of the basic principles governing alloy selection for the process industries was given.

Reported by James W. Bulls

NEW YORK

An attendance well above average and a rapid barrage of questions from the floor highlighted the meeting of Feb. 20. The speaker was C. W. Bendigo, American Cyanamid Co., formerly chief editor of Textile World. He was introduced by A. G. Parker, of the Industrial Division of Foster Wheeler Corp.

Mr. Bendigo predicted that production of the newer synthetic fibers (excluding rayon and acetate) will roughly double

(*Continued on page 52*)

Building a wall against CORROSION... with ATLAS LININGS

The steel vessel being lined above is to be used in the production of a corrosive salt . . . it will hold sulfuric acid at high temperatures and give good service indefinitely.

As the basic lining for this application, ATLAS recommends *Atlastavon* . . . a tough, durable, dense and homogeneous sheet that gives superior service as a lining material. *Atlastavon* has another advantage of permanence that overcomes the pitfall of many chemically inert materials: By ATLAS techniques, *Atlastavon* can be *permanently and positively bonded to steel.* In *Atlastavon*, you have a permanent investment in a lining that will give broad chemical resistance and not separate from the member it is protecting.

Above, acid-proof brick sheathing is also being installed with ATLAS corrosion-proof cement. Sheathing protects the lining from excessive heat, abrasion or accidental damage. It's an extra preventive measure . . . but it's well to know that every aspect is considered by ATLAS. Nothing is overlooked to assure the long-term success of your installation.

ATLASTAVON FOR STEEL VESSELS is available in two compositions which together provide chemical resistance over an extremely wide range of corrosives. Used with or without brick sheathing.

ATLASTISEAL FOR CONCRETE TANKS consists of a primer, membrane layers, and a reinforcing layer of ATLAS products with the added protection of acid-proof brick and cement.

INFORMATIVE DATA on ATLAS linings for steel or concrete vessels is available in Bulletin 4-2. Send for your copy.

ATLAS PRODUCTS STAND ...between your process and corrosion

ATLAS MINERAL PRODUCTS COMPANY

MERTZTOWN PENNSYLVANIA

HOUSTON 1, TEXAS

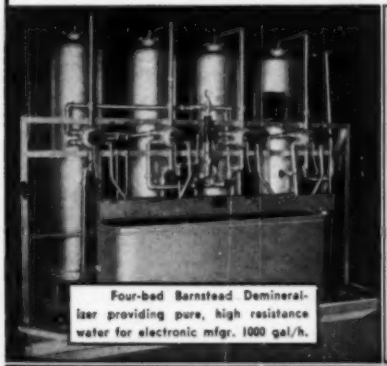
Corrosion-proof: Cements—Coatings—Vessel Linings

BARNSTEAD DEMINERALIZERS

PROVIDE LOW-COST PURE WATER

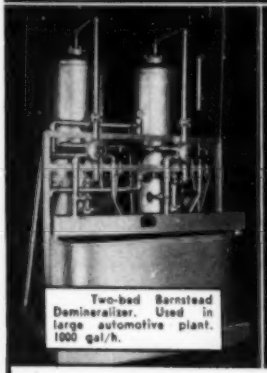
for • Electroplating • Anodizing
• Photographic Solutions
• Salt-free Rinse Water • Silvering

And Hundreds of Other Applications



Four-bed Barnstead Demineralizer providing pure, high resistance water for electronic mfgr. 1000 gal/h.

Barnstead Four-Bed Demineralizer provides pure water for hot seal tank in anodizing. 30 gal/h.



Two-bed Barnstead Demineralizer. Used in large automotive plant. 1000 gal/h.

Four-bed Barnstead Demineralizer produces pure, sparkling-clear rinse water for pharmaceutical plant. 200 gal/h.

Selection of the best size and type of demineralizer for your operation depends on the nature of your raw water supply, flow rate needed, daily demand, and degree of purity required. Send a sample of your water to our Laboratory and Barnstead Engineers will perform the necessary analysis without obligation.

PROMPT DELIVERIES WRITE FOR FREE CATALOG

Barnstead STILL & STERILIZER CO.

82 Lanesville Terrace, Forest Hills, Boston 31, Mass.

LOCAL SECTION NEWS

(*Continued from page* 51)

over the next four-year period. Percentagewise, the most rapid growth will probably occur in the acrylic fibers. The acrylics, the first important synthetics to compete with wool as warmth fibers, will be made predominantly in staple form, for such uses as blankets and outer garments. The major growth in nylon, on the other hand, will be in continuous filament rather than staple. Also contributing importantly to the growth in this field will be polyester and glass fibers.

Reported by C. H. Chilton and A. G. Parker

CHARLESTON

The third meeting of the year was held Jan. 15, 1952, at the Charleston Recreation Center, with an attendance of 163 members and guests.

Ralph Ross of the Public Relations Committee reported that plans are being made for a series of four radio programs, prepared by the Committee, to be broadcast by radio station WCHS. The purpose of the programs is to interest high school students in chemical engineering as a vocation.

Kanawha Valley Technical Council Committee Chairman R. G. Edmonds reported on developments for the local observance of Engineers' Week. He asked that members of the Charleston Section support the observance by orally publicizing the exhibits which were displayed in the rotunda of the West Virginia State Capitol. This Section participated in the technical session Feb. 23 by presenting a symposium on "The Place of the Chemical Engineer in Industry."

Following the business session the meeting was addressed by C. Rogers McCullough on "Atomic Energy for Peaceful Purposes." Dr. McCullough is with the Monsanto Chemical Co. and is now director of its atomic energy project with Union Electric Co.

After introductory remarks on recent advances and current activities in the field of power from atomic, or nuclear, energy, Dr. McCullough discussed some of the characteristics of nuclear energy.

Reported by G. K. S. Connolly

NORTHERN CALIFORNIA

The importance and growth of the synthetic ammonia industry was emphasized by Frank D. Kuenzly, plant manager of the Shell Chemical plant at Ventura, Calif., in a talk before this Section at a dinner meeting held Feb. 18 at the Engineers' Club in San Francisco. Approximately 140 members and guests

heard Mr. Kuenzly discuss the history of synthetic ammonia, the various processes used to manufacture it, and recent developments in the field.

The first meeting of the year was held Jan. 21 at the Engineers' Club in San Francisco. More than 120 members and guests attended the dinner. The speaker of the evening was Harry L. Coderre of Rohrer, Hibler and Replogle, consulting psychologists, who discussed "The Role of the Psychologist in Industry." Mr. Coderre described the aims of industrial psychological consultants and explained the methods used.

New officers are:

Chairman—H. D. Guthrie, Shell Development Co.
Vice-Chairman—C. R. Wilke, University of California.
Sec'y-Treas.—E. B. Chiswell, California Research Corp.
Executive Comm.—T. E. Drisko, Dow Chemical Co.
R. W. Lundeen, Dow Chemical Co.
F. W. Meyer, Bechtel Corp.
R. I. Stirton, Oronite Chemical Co.

Reported by D. F. Rynning

MIDLAND

The third meeting of this section (in formation) was held Jan. 24, at the auditorium of The Dow Chemical Co., Midland, Mich. Eighty-five members and guests were present. Prof. C. E. Lapple of Ohio State University spoke on "The Design and Operation of Centrifugal Collectors for Dusts and Mists." His talk stressed necessity of getting representative samples of the material to be collected as well as a size and weight distribution of the particles.

During the shoft business meeting held before the talk, John Wardwell, was elected secretary-treasurer to complete the term of Dr. James Kapnicky who has moved to West Virginia.

The second meeting was held Nov. 29, 1951, at the auditorium of The Dow Chemical Co., at which 80 members and guests listened to Prof. Robert Marshall, Jr., of the University of Wisconsin, speak on "Drying."

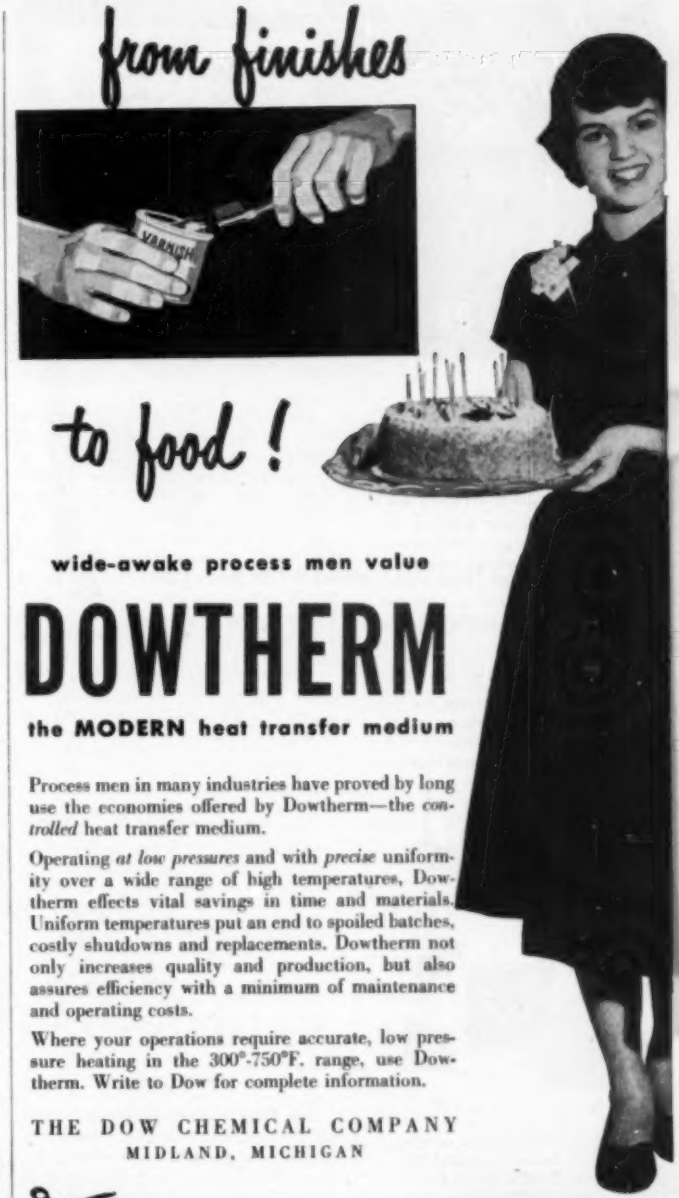
Reported by Raymond Duddleston

CHICAGO

E. C. Crocker was the speaker at the Feb. 20 meeting at the Western Society of Engineers' suite. Dr. Crocker, associated with Arthur D. Little, Inc., talked on flavors and odors, and explained the four elements of taste, their tongue localization, and many chemical phenomena of this sense. Odors cannot be classified as simply as taste; the human can recognize more than 100,000 different odors, he said.

Reported by Thorpe Dresser

(*More Local Section News on page* 54)



wide-awake process men value

DOWTHERM

the MODERN heat transfer medium

Process men in many industries have proved by long use the economies offered by Dowtherm—the *controlled* heat transfer medium.

Operating *at low pressures* and with *precise* uniformity over a wide range of high temperatures, Dowtherm effects vital savings in time and materials. Uniform temperatures put an end to spoiled batches, costly shutdowns and replacements. Dowtherm not only increases quality and production, but also assures efficiency with a minimum of maintenance and operating costs.

Where your operations require accurate, low pressure heating in the 300°-750°F. range, use Dowtherm. Write to Dow for complete information.

THE DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN

THE DOW CHEMICAL COMPANY
DEPT. DO-11A
MIDLAND, MICH.
"Tell me more about DOWTHERM."

Name _____ Title _____
Company _____
Address _____
City _____ State _____

DOW
CHEMICALS
INDISPENSABLE TO INDUSTRY AND AGRICULTURE

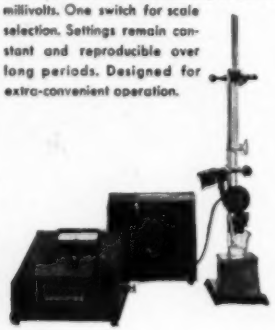
Much More than Accurate

COLEMAN
AC pH METER
AND
AUTOTRATOR

precision plus ultra convenience at a practical price!

COLEMAN AUTOTRATOR
makes automatic titration practical for every laboratory, large or small. Quick and easy end-point settings, completely automatic operation, high volumetric accuracy, low cost—these make the Autotrator a time and money-saving tool for the working chemist.

COLEMAN AC pH METER
Instant reading . . . line operated and unaffected by voltage variations. Accurate to 0.05 pH. Dual scale meter calibrated 0-8 and 6-14 for continuous reading of pH or millivolts. One switch for scale selection. Settings remain constant and reproducible over long periods. Designed for extra-convenient operation.



For complete information on this "Laboratory Team," write Dept. Q. for Bulletin B-221 and B-223.

COLEMAN INSTRUMENTS
MAYWOOD, ILLINOIS

NORTHEASTERN NEW YORK CHEMICAL ENGINEERS' CLUB

The fifth meeting of this Club was held in Troy, N. Y., at Rensselaer Polytechnic Institute, Feb. 19. The 36 members present heard a talk by Miles Martin of the General Electric Research Laboratory on "Pitfalls of Technical Report Writing and Speaking." For the past five years Dr. Martin has been editor of technical publications at the Research Lab. The talk was directly concerned with problems that confront the engineer and scientist whenever they attempt to convey information by speaking or writing.

The club name has been changed from Capitol District Chemical Engineers' Club.

On Jan. 22 the Club held a meeting. The 44 members present heard an illustrated talk on the "Disposal of Radioactive Liquid and Solid Wastes" by Robert H. Simon, head of the Waste Process Studies Unit of the Chemistry and Chemical Engineering Section of the Knolls Atomic Power Laboratory. His lecture dealt with concentration of highly radioactive liquids prior to storage in underground tanks, evaporation of low and medium level radioactive liquids, etc.

At a prior meeting 50 members heard Lewis Mahony, application engineer of the Mixing Equipment Co., talk on practical aspects of mixing.

Officers for 1952 are:

Chairman — Burton Coplan, Knolls Atomic Power Laboratory
Vice-Chairman—Laverne Heaps, General Electric Co.
Secretary — Roger Larson, Knolls Atomic Power Laboratory
Treasurer—William Shuster, Rensselaer Polytechnic Institute
Executive Comm.—Robert H. Simon, Knolls Atomic Power Laboratory
Thomas Tully, General Aniline Works
Donald Waterfield, Behr-Manning Corp.

Reported by R. E. Larson, L. P. Heaps

ST. LOUIS

The Feb. 19 meeting of this Section held at the York Hotel was attended by 81 members and guests. Nathan Kohn, Jr., of Washington University, spoke on "Tools That Expedite Professional Advancement." Dr. Kohn touched briefly on reading speed improvement, and the development of testing procedures to determine aptitudes and skills. Dr. Kohn expressed the opinion that the chemical industry could utilize its technical manpower better by improving its methods of training technical people for administrative jobs.

Reported by D. S. Weddell

BETTER NOZZLES
for every spraying process

Here's why Binks Rotojet nozzles are a better buy for applications involving oxidation, evaporation, spraying, washing, cooling, condensing, refrigeration:

Clog-proof: Smooth construction plus whirling motion within nozzle makes Binks nozzles self-cleaning.

Full fluid break-up: Binks nozzles provide hollow or solid cone sprays, also flat spray patterns.

Long, trouble-free life: Simple design ...no moving parts...thick metal sections assure extra long life.

Wide range of sizes...types: Selection of orifice diameters, types of nozzles, and pipe connection sizes from ⅛" to 2½".

Special alloys: Binks nozzles can be supplied in any machinable alloy, obtainable in bar stock. Nozzles are regularly made of high quality brass.

Send today for your free copies of Bulletins 10 and 12, which describe Binks Rotojet nozzles fully, with complete engineering data for each size. Please state capacity required and application intended.

Binks MANUFACTURING CO.

A COMPLETE LINE OF COOLING TOWERS • SPRAY NOZZLES
3114-32 Carroll Ave., Chicago 12, Illinois
REPRESENTATIVES IN PRINCIPAL CITIES

NASHVILLE SOCIETY OF CHEMICAL ENGINEERS

The fourth meeting of the season was held Jan. 17, 1952, and R. N. Lyon of the Oak Ridge National Laboratory spoke on "Liquid Metals Heat Transfer." Dr. Lyon's talk included theoretical considerations, corrosion problems and the application of electromagnetic pumps. Twenty-six members and guests attended.

The third meeting of the fall season was held Dec. 6, 1951. Christian H. Aall of the Monsanto Chemical Co. talked on "Electric Furnaces and Electrothermal Processes." Dr. Aall's lecture included the principles and design of electric furnaces and their application in producing ferrosilicon, calcium carbide, and phosphorus. Twenty-five members and several students attended.

Previous meetings of the fall season included a talk by N. A. Copeland of the Du Pont Co. on "Chemical Plant Design" and a panel discussion, led by Dr. E. E. Litkenhous, chemical engineering department head, Vanderbilt University, on "What Does Industry Require of a Chemical Engineer?"

Reported by W. K. Lautner

NATIONAL CAPITAL

A meeting was held Jan. 14, 1952, at the Army-Navy Club, Washington, D. C. Francis J. Curtis, Past President of A.I.Ch.E. and vice-president of Monsanto Chemical Co., until recently assistant administrator in charge of the chemicals, rubber, and forest products division of N.P.A., was the speaker. His subject was "Progress in Chemical Mobilization."

Reported by D. P. Herron

I.G.T. BULLETINS RESUME

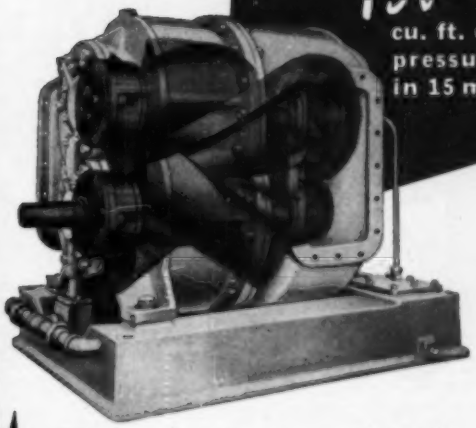
The Institute of Gas Technology, Chicago, has resumed publication of its Research Bulletin Series, suspended since 1948. Reports on the intervening three years of research are being issued in a series of 16 bulletins.

Two of them, "Sulfur Poisoning of Nickel Catalysts," by C. H. Riesz, H. A. Dirksen, and W. J. Kirkpatrick, and "Expansion Behavior of Coal During Carbonization," by O. P. Brysch and W. E. Ball, have already been published. A third, "Pilot Plant Catalytic Gasification of Hydrocarbons," by C. H. Riesz, P. C. Lurie, C. L. Tsaros and E. S. Pettyjohn, is in preparation.

C. J. T. MACKIE DIES

C. J. T. Mackie, assistant secretary of The Institution of Chemical Engineers, London, died Jan. 8, according to word received here. Mr. Mackie became assistant secretary of the British chemical engineers in 1924.

this STANDARDAIRE handled 1⅓ billion cu. ft. of high pressure air in 15 months



Then we dismantled the unit . . . **FOUND IT AS GOOD AS NEW**

- Unit 9B16-213, for 15 months of day and night outdoor service, was operated beyond its rated capacity to meet unforseen demands. It was replaced by a larger Standardaire Blower. The engineer of this plant asked that the hard working unit be sealed and returned to our factory so that he personally could observe the dis-assembly and measurements for wear.
- Main and Gate Rotors like new—interior of blower completely dry and free of oil—no wear in other internal parts.
- Timing Gears on Gate and Main Rotors—wear very slight—no increase in back lash could be detected.
- Axial clearance of Main Rotor Shaft Thrust-Radial Bearing, increased less than .0005"—other bearings in perfect order.
- Even at the extremely high peripheral speed of these gears, they were found to be very quiet in service.
- Standardaire Blowers are sturdy—precision built units with proved staying power.

Write for specific data—Dept. F-14. Read Standard Corporation, 370 Lexington Ave., New York 17, N. Y.

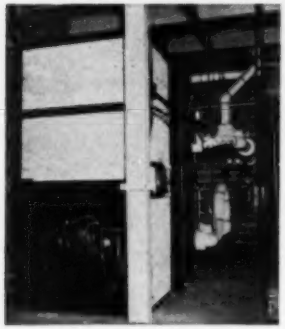
AXIAL FLOW STANDARDAIRE BLOWER

BLOWER-STOKER DIVISION

READ STANDARD CORPORATION

NEW YORK • CHICAGO • ERIE • YORK • LOS ANGELES

MERRILL PROCESS
Circulating Hot Oil System



Product Temperatures to 550°F

Negligible Pressure only a few pounds

Controlled heat input within a few degrees

Safe
Versatile
Dependable

Does your process require a smooth, even flow of heat at temperatures far beyond the range of steam, with negligible pressure, and without the hazard of direct fire, and without objectionable odors?

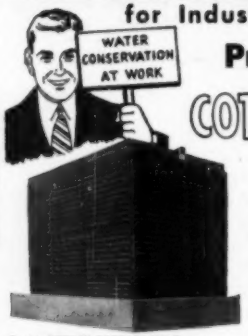
MERRILL PROCESS Is The Answer

Versatile—may be used on product equipment that cannot withstand pressure such as glass-lined vessels.
Safe at all times. Steel pumps, valves and fittings.
Dependable—smooth, quiet delivery of heat.
Typical uses—evaporating, distilling, drying, coating, melting.
Full line of jacketed cocks, fittings and pipe too.

Write for Merrill Process Bulletin 145 or Jacketed Fittings Bulletin 152

PARKS-CRAMER COMPANY, FITCHBURG, MASS.

High Operating Efficiency
for Industrial Applications



Series "SR12" COTOSPRAY* Tower

Pritchard COTOSPRAY* Quality Cooling Towers

Pritchard offers you a complete line of COTOSPRAY* Cooling Towers, available either as standard spray towers or with coil systems in basin for closed system cooling of liquids or gases. Each tower is designed for a specific industrial application with resultant higher operating efficiency. Highest quality, long-life Redwood. Steel pipe distribution system. Non-clogging bronze spray nozzles. 3 to 221 tons capacity. Investigate Pritchard COTOSPRAY* Towers today! Write for bulletin 5.9.083.

*Trademark

Cooling Towers
Gas & Air Treating
Specialized Heat Exchangers

J.F. Pritchard & Co.
EQUIPMENT DIVISION
Dept. No. 220 906 Grand Ave., Kansas City 6, Mo.

Sales Offices: CHICAGO • HOUSTON • NEW YORK • PITTSBURGH
TULSA • ST. LOUIS • Representatives in Principal Cities from Coast to Coast

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before April 15, 1952, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Atkinson, Ralph G., *Maple Heights, Ohio*
Best, George E., *Baltimore, Md.*
Bondi, A. Arnold, *Emeryville, Calif.*
Boyd, Noel F., *Pittsburgh, Pa.*
Carder, C. R., Jr., *So. Charleston, W. Va.*
Coffey, Joseph F., *Whiting, Ind.*
Crymble, John F., *Salem, N. J.*
DeForest, Elbert M., *Wichita, Kan.*
Dickinson, Norman L., *New York, N. Y.*
Donnalley, James R., Jr., *Schenectady, N. Y.*
Eckerson, Bruce A., *La Habra, Calif.*
Edwards, Richard M., *St. Louis, Mo.*
Erickson, Raymond A., *Ridgewood, N. J.*
Fair, Harry G., *Kansas City, Kan.*
Forsyth, Paul S., *Washington, D. C.*
Garbo, Paul W., *New York, N. Y.*
Gester, George C., Jr., *Berkeley, Calif.*
Glover, Donald W., *Mullica Hill, N. J.*
Gohr, E. J., *New York, N. Y.*
Grosselfinger, Frederick B., *New York, N. Y.*
Hanchett, Arnold, *Syracuse, N. Y.*
High, Hamilton M., Jr., *Orange, Tex.*
Holzschuh, Andrew A., *Midland, Mich.*
Howell, Charles M., *Orono, Me.*
Jackson, William K., *Big Spring, Tex.*
Johnston, A. H., *Arvida, P. Q., Canada*
Karkalits, O. Carroll, *So. Plainfield, N. J.*
Kwauk, Mooson, *New York, N. Y.*
Landry, Bertrand A., *Columbus, Ohio*
Lazare, Leon, *Westbury, N. Y.*
Lindstedt, Paul M., *Akron, Ohio*
Mahoney, Frederick L., *Westfield, N. J.*
Martz, Robert W., *New York, N. Y.*
Middleton, Arthur H., *Baton Rouge, La.*
Miller, D. J., *Long Beach, Calif.*
Moeller, W. Paul, *W. Orange, N. J.*
Morris, Boyd, *Rifle, Col.*
Nemeth, Joseph F., *St. Louis, Mo.*
Norris, Richard S., Jr., *Port Arthur, Tex.*
Obey, James H., *Pittsburgh, Pa.*
Parker, Walter B., *Cambridge, Mass.*
Purvin, Robert L., *Dallas, Tex.*
Ransom, Edwin A., *Pasadena, Tex.*
Ray, Louis F., *Wilmington, Del.*
Rhode, Judson C., *Charleston, W. Va.*
Rodekohr, H. M., *Alhambra, Calif.*
Rogers, Thomas H., Jr., *Akron, Ohio*
Russell, John W., *Robinson, Ill.*
Schacht, A. H., Jr., *Altadena, Calif.*
Sidwell, W. K., *Newark, Ohio*
Stark, William F., *Philadelphia, Pa.*
Strawn, Max, *Glen Rock, N. J.*
Underwood, Murray, *Springfield, Mass.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Calloway, Foster F., *St. Albans, W. Va.*
Eason, Walter E., Jr., *Baltimore, Md.*
Norbert, C. P., *Baltimore, Md.*
Remsen, John G., *Scranton, Pa.*
Snyder, Victor P., *Harvey, Ill.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Adams, Donald A., *Wilmington, Del.*
Albelda, Beto, *Forest Hills, N. Y.*
Allen, A. Kent, *Monroe, La.*

Anders, C. William, *Rochester, N. Y.*
Anderson, Fletcher N., *St. Louis, Mo.*
Barone, Louis J., *Brooklyn, N. Y.*
Batty, Reginald W., Jr., *Port Arthur, Tex.*
Bender, Stuart L., *Midland, Mich.*
Benedict, David C., *Upper Darby, Pa.*
Blase, Edwin Wm., *Carle Place, N. Y.*
Blomshield, John H., *Scotia, N. Y.*
Bond, John R., *Midland, Mich.*
Bradshaw, John R., *Wilmington, Del.*
Breithaupt, C. Edward, *Waynesboro, Va.*
Brewster, Harold M., *Passaic, N. J.*
Brewton, J. C., Jr., *Pasadena, Tex.*
Butts, Charles E., *St. Louis, Mo.*
Corson, William B., *Stamford, Conn.*
Coykendall, John W., *Richmond, Calif.*
Croke, Richard J., *Brooklyn, N. Y.*
Daly, James C., *St. Joseph, Mo.*
Deasy, John J., Jr., *Watervliet, N. Y.*
Donner, Thomas B., Jr., *University City, Mo.*
Duffer, James C., *Springdale, Pa.*
Eargle, John C., Jr., *Oak Ridge, Tenn.*
Eckenrode, John E., *Baltimore, Md.*
Edwards, Dan J., *Pottstown, Pa.*
Erskine, William W., *Buffalo, N. Y.*
Finch, Robert E., *Terre Haute, Ind.*
Finney, Bruce C., *Columbus, Ohio*
Fivel, Herschel Jack, *Lakewood, Ohio*
Geissler, Gary, *Metuchen, N. J.*
Glasser, Jack I., *Ann Arbor, Mich.*
Goudreau, Peter A., *Detroit, Mich.*
Graham, Eldon L., *Midland, Mich.*
Grosso, Michael J., *Bayonne, N. J.*
Gully, Arnold J., *State College, Miss.*
Harper, William S., *Chicago, Ill.*
Harris, Ray W., *Lockport, N. Y.*
Harris, Richard L., *Terre Haute, Ind.*
Hartzog, B. H., *Texas City, Tex.*
Haun, James W., *Longmeadow, Mass.*
Hickerson, Roger N., *Magnolia, Ark.*
Hirschland, Henry E., *Cranford, N. J.*
Howard, William C., Jr., *Medford, N. J.*
Kelly, Brian M., *Newark, N. J.*
Kieran, William M., *Detroit, Mich.*
Kimball, Emory H., *Webster Groves, Mo.*
King, James Dorsey, *St. Louis, Mo.*
King, Melvin E., *Aliquippa, Pa.*
Laursen, Fenn, *New Castle, Del.*
Leber, Glenn W., *Texas City, Tex.*
Leslie, Richard L., *Springfield, Ohio*
Lockwood, R. A., *Cupertoni, Calif.*
London, Alex, *New York, N. Y.*
Long, John R., *Wilmington, Del.*
Lucchetti, Robert J., *Chicago, Ill.*
MacAllister, Edward N., *Cranford, N. J.*
MacBeth, Gordon, *Midland, Mich.*
Mack, Joseph K., *Cleveland, Ohio*
MacQueen, Donald K., *Bartlesville, Okla.*
Magers, W. J., *Marcus Hook, Pa.*
Martin, Edward G., *Astoria, N. Y.*
Miller, James A., *Kelso, Wash.*
Mills, J. John, *St. Louis, Mo.*
Milwee, John B., *Texas City, Tex.*
Moison, Robert L., *Wilmington, Del.*
Moorman, Wallace B., *Baton Rouge, La.*
Morris, James P., *New York, N. Y.*
Moser, Roger A., *Baton Rouge, La.*
Nadaskay, R. J., *Union, N. J.*
Needles, Robert C., *Akron, Ohio*
Nelson, James R., *Barberton, Ohio*
Newton, Donald G., *Pennsauken, N. J.*
O'Brien, Victor J., *Whiting, Ind.*
Ottoboni, Fred L., Jr., *Santa Rosa, Calif.*
Overberger, William F., *Cuyahoga Falls, Ohio*
Paulin, A. W., *So. Charleston, W. Va.*
Perloff, Alvin, *Washington, D. C.*
Petrone, Louis, *Brooklyn, N. Y.*
Pliner, Leon Milton, *Shreveport, La.*
Pyle, Robert E., *Morgantown, W. Va.*

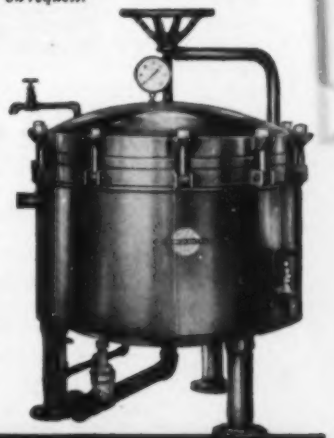
Few other industries require the painstaking supervision, accuracy, or sanitation that is necessary in the production of drugs used to perform "everyday miracles." Yet in spite of this, each of the companies whose trade mark is shown above, day after day, year after year, produces pharmaceuticals that *never meet anything less than the highest standards of purity.*

Of course, the plants operated by these companies are models of precision, planned to achieve the greatest possible efficiency with the finest equipment available. That's why, in each of these plants, you will find Sparkler filters handling difficult liquid filtration jobs.

It is important to remember that Sparkler filters were designed with the same goals in mind — accuracy and sanitation — that are accepted as a fundamental part of the drug industry. They utilize the patented Sparkler horizontal plate principle to provide firm support for the filter media and filter aid. This horizontal surface permits the formation of a stronger, completely uniform cake that will not slip or crack even under intermittent operation. Thus, filtration quality through the entire cake is constant, and can easily be regulated by varying the cake density.

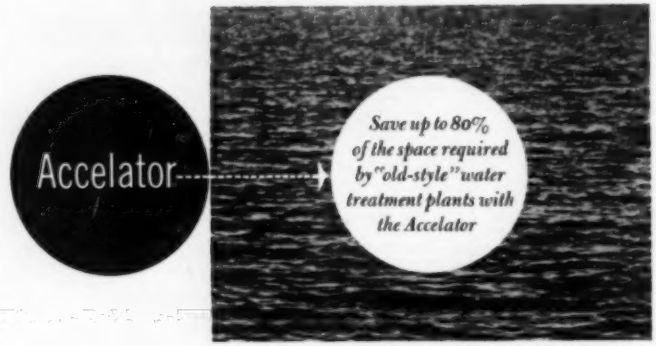
Plates are assembled one above the other and are fastened together in cartridge form, making it extremely simple to remove them from the filter for cleaning. Other Sparkler features include compact, neat design, high flow rates and low operating cost.

For full information, write to Mr. Eric Anderson. New catalog is available on request.



Regester, George L., *Catonsville, Md.*
Reid, David W., *Savannah, Ga.*
Rhoades, Edgar F., *Ft. McClellan, Ala.*
Robertson, William Barry, *Powell, Tenn.*
Ross, E. A., *Charlestown, Ind.*
Ross, Jack E., *Richmond Hill, N. Y.*
Schafer, Alexander C., *Schenectady, N. Y.*
Schneider, Milton D., *Ponca City, Okla.*
Schwartz, Daniel, *Oak Ridge, Tenn.*
Shannon, Robert L., *Steubenville, Ohio*
Shen, Chung Yu, *Louisville, Ky.*
Skinner, William R., *Port Arthur, Tex.*
Smith, D. Russell, *Chicago, Ill.*
Smith, William M., *Avon, Conn.*
Stafford, E. A., *Baton Rouge, La.*
Stiefel, Maurice B., *Washington, D. C.*
Sullivan, H. D., *Lake Jackson, Tex.*
Sykes, Wendell G., *Scituate, Mass.*
Szczepanik, Patrick J., *Detroit, Mich.*
Tackett, Thomas Nelson III, *Texas City, Tex.*
Talbot, Frederick R., *Akron, Ohio*
Tashjian, Manoog George, *Bronx, N. Y.*
Trowbridge, Malcolm, Jr., *Akron, Ohio*
Trumbull, John H., *Edgewater Park, N. J.*
Tunkel, Steven J., *Morristown, N. J.*
Turner, Gilbert M., *Wilmington, Del.*
Varley, Kenneth L., *Stow, Ohio*
Weber, Frederick R., *Watertown, Mass.*
Weber, Lester G., *St. Louis, Mo.*
Wheeler, John J., *Rochester, N. Y.*
Zeyfang, Robert W., *Rochville, Ind.*

RUNNING OUT OF GROUND?



...and the Accelator is built only by **Infilco!**

Proved installations throughout the world in over 1,500 plants, the space-saving economics of the Accelator is but one of the many advantages thoroughly described by Infilco Bulletin 1825. Write for your copy today.

INFILCO

INFILCO INC. *Tucson, Arizona* | *Plants in Chicago & Joliet, Illinois*

FIELD ENGINEERING OFFICES IN 26 PRINCIPAL CITIES

World's Leading Manufacturers of Water Conditioning and Waste-Treating Equipment

Secretary's Report

S. L. TYLER

The Executive Committee of the Institute met at The Chemists' Club, New York, Feb. 8. The agenda covered mainly routine matters which must be handled periodically.

All those whose names appeared in the January Issue of "C.E.P." as candidates for membership were elected to the grades as indicated.

The Secretary reported satisfactory operations of the Engineering Manpower Commission of E.J.C. and the return of the money originally appropriated for the starting of the Manpower Commission as it is now on a self-supporting basis.

The Secretary reported a small surplus of receipts over operating expenses for the Atlantic City meeting in the amount of $388.79 and a surplus of $1198.91 from the Rochester meeting. In accordance with usual practice this money was added to the Institute Meetings Account and is not to be used for operating expenses.

In accordance with action of Council there was a final revision of the By-Laws and they were ultimately approved and submitted to Council for a final mail vote.

Ten members of the Institute were added to the Suspense List because of their entrance into the Armed Forces.

Four elections to membership were rescinded because no reply was received to notification of election.

Thirty-seven resignations were received and accepted.

Upon recommendation of C. C. Monrad, chairman of the Student Chapters Committee, H. Y. Krinsky was appointed counselor of the student chapter at Pratt Institute to succeed R. F. Shaffer.

A few additional committee appointments were made.

A report of the Committee on Unity of the Engineering Profession was received and a subcommittee consisting of the following was appointed to study these recommendations and report to Council not later than May 1: L. W. Bass, chairman, W. L. McCabe, T. H. Chilton, S. L. Tyler, W. N. Jones, C. G. Kirkbride, P. D. V. Manning, W. I. Burt and R. P. Kite.

COMMITTEE ON TESTING TECHNIQUES REPORTS

W. T. Dixon, manager, design division, engineering and construction department, Atlantic Refining Co. and a director of the Institute reported consid-

(*Continued on page* 61)

INDUSTRY CONTRIBUTES DISTILLATION FUNDS

Funds from the chemical and petroleum industry for support of a research program on bubble-plate efficiency, fostered by the A.I.Ch.E., have now reached one-third of the amount necessary according to Walter E. Lobo, director of chemical engineering department, of M. W. Kellogg Co., and chairman of the A.I.Ch.E. Research Committee. "With more than two-thirds of the companies solicited yet to respond, the possibilities of a successful drive are practically guaranteed," he said.

As reported in the November, 1951, issue of "C.E.P.," the research committee of the Institute was appointed in July, 1950, "to foster research projects in chemical engineering which by their scope, complexity, or general nature, were such that no single institution or company could afford a comprehensive planned research program."

The first problem the committee decided on was a basic program of research on the effect of tray design and system properties on tray efficiency, both in fractionation and absorption.

Mr. Lobo's committee began actively, to solicit funds in January of this year, and in a month had more than one-third of the necessary $100,000 that is being sought.

Contributions and pledges of support have been received from the following companies:

The Barrett Division, Allied Chemical & Dye Corp., Carbide and Carbon Chemicals Co., division of Union Carbide & Carbon Corp., Hercules Powder Co., Inc., New Port Industries, Pittsburgh Plate Glass Co., Sharples Chemicals, Inc., M. W. Kellogg Co., Inc., Gulf Oil Corp., Standard Oil Co., and Standard Oil Development Co.

SAVE THOSE BACK ISSUES

Every so often an unprecedented demand for a particular issue, or an unexpected influx of new subscribers and members puts the editor in the embarrassing position of running out of copies of Chemical Engineering Progress. This has happened several times in our short history and if members have copies of any of the following issues, we would be glad to purchase them. The issues which we need and for which we will pay 75 cents each, are: January, 1949; October and November, 1950, and February and March issues of 1951.

All these issues were overprinted to a great extent, but because of features and other demands, single copy sales, etc., they were completely exhausted in a short time.

for valving corrosive and "hard-to-handle" fluids . . .

HILLS-McCANNA

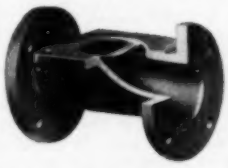
offers over 20,000 different "custom-made" assemblies on a standardized basis

32 standard operators

Methods of operation for Hills-McCanna Valves include handwheel and lever operators, sliding stem, air and hydraulic cylinders, diaphragm motors and electric motors in a variety of types.

14 standard diaphragms

Diaphragms, the heart of Hills-McCanna Valves, are offered in the widest choice to best suit your individual needs; 5 types of rubber, 3 of Neoprene plus Hycar, butyl, Tygon, Compar, special polyethylene and Kel-F.



48 standard body materials

Bodies for Hills-McCanna valves are furnished in cast iron, with or without such linings as rubber, glass, lead, etc.; in any machinable alloy or in such materials as Karbate, stoneware, porcelain, etc.

By offering such a broad selection of operators, diaphragms and bodies, Hills-McCanna is able to furnish so many standard combinations that the user is in the position of being able, in most cases, to find the exact valve that best fits his individual requirements. There is virtually never any need to adapt to your service a valve developed for someone else's needs.

The 36 page catalog No. V-52 gives full details on all Hills-McCanna Valves. Write for your copy. HILLS-McCANNA CO., 2438 W. Nelson St., Chicago 18, Illinois.

HILLS-McCANNA

saunders patent diaphragm valves

Also Manufacturers of Proportioning Pumps

Force Feed Lubricators • Magnesium Alloy Castings

A LOCAL SECTION SPONSORS A LECTURE SERIES

D. S. BRUCE †

Hercules Powder Company, Parlin, New Jersey

A CHEMICAL Engineering Lecture Series can be operated and some contribution can be made to the professional development of all participating. This is the conclusion we in the New Jersey Section can draw from our experience in sponsoring such a series.

EDITOR'S NOTE

Here in the fourth of the series of articles on A.I.Ch.E. activities, D. S. Bruce, associated with the Hercules Powder Co., stresses a section's responsibility in the matter of professional development of its members. It is his belief that despite the many problems involved in setting up a chemical engineering lecture series, the New Jersey Section made a success of this first try—financially also—and should be prepared to go forward with another such series that will satisfy all members in its coverage and its practicality. The first article on Institute activities was run in March, 1951, where G. G. Brown discussed graduate education in chemical engineering. In the second, run in September, 1951, K. A. Kobe told of the cooperation of local sections and industry in establishing educational centers. In the December, 1951, issue L. P. Scoville related some of the things that have been done by the New York Section for students in the metropolitan area.

Looking Backward

Going back to the days when the idea was first proposed—the idea of a lecture series was not an original one for several lecture series had previously been sponsored by other technical groups—the Executive Committee of the New Jersey Section requested that the writer study the question and make a recommendation. After attending several lectures, principally those of the local A.C.S. and discussing the matter with members responsible for their operation, a recommendation was made. This defined the need for professional improvement which to a limited extent could be served by a Chemical Engineering Lecture Series. Further, that the local section had some responsibility for professional development that could be discharged partially by offering such a lecture program and one which would not duplicate any operating within the section limits. Of course, the financial success of the venture presented something of a problem but the Executive Committee tentatively agreed that the financial loss to the section should be limited to no more than $250, and that the program be undertaken in the first quarter of 1951.

Committee at Work

With this background a committee was formed with the author as chairman, Prof. G. C. Keefe, Newark College of Engineering, and Prof. J. O. Stett of Rutgers. The first and most important action undertaken was the selection of a program. Obviously the choice of subject matter required considerable study, and time did not permit an opinion poll.

The first discussion involved the scope of the program. With a restricted liability it was felt that the program should be kept to five lectures. It was then agreed, since this was our first venture, that we should keep our program as fundamental and as practical as possible, and that we limit our consideration to some phase of the Unit Operations. After examining the character of section membership, we decided that our program would concentrate on those unit operations which are controlled by the phenomenon of diffusion. A program was outlined. The first lecture laid the groundwork and consisted of a general theoretical study of the basic phenomenon of diffusion which would cover as much of the theory of mass transfer as time would permit. The remaining four lectures would deal in turn with the correlation of the theory with practical applications in the following unit operations:

Second Lecture—Absorption
Third Lecture—Adsorption
Fourth Lecture—Distillation
Fifth Lecture—Drying

The next and obvious problem was the engagement of speakers. Our objectives were first to obtain men recognized in their respective fields who would be willing to participate, and second to get as much balance between academic and industrial background as possible. The following men were asked to participate in the program.

First—Prof. J. Edward Vivian, M.I.T.
Second—Dr. John B. Tepe, Du Pont
Third—Prof. Charles M. Mantell, Newark College of Engineering
Fourth—J. R. Minevitch, E. G. Badger, Division of Stone & Webster
Fifth—Dr. W. R. Marshall, University of Wisconsin

Each participating lecturer was requested to prepare notes on his subject, which were duplicated and distributed just prior to the lecture. A modest fee, together with reimbursement for necessary expenses, was offered. It was decided to schedule the lectures at two different locations, thus limiting the inconvenience of any geographic group. Both Newark College of Engineering at Newark, N. J., and Rutgers University at New Brunswick, N. J., generously contributed the use of an auditorium.

Some Tangible Results

From a financial point of view it was possible to give a favorable report to the Executive Committee. Attendance at the lectures totaled 835 for an average of 167 per lecture. Section members were charged $5.00 and non-members were charged $6.00 for the five lectures. This fee included a set of lecture notes. Individual lecture tickets were available for $2.00 apiece. A total of 290 series tickets was sold and 32 single lecture tickets were sold. By taking advantage of some of the industrial and academic friends of the section we were able to minimize the cost of duplicating the lecture notes. Thus, the section was able to reduce expenses to a minimum and turn in a net balance of more than $1,000.

Intangibles of the Enterprise

It is rather difficult to evaluate accurately the over-all results of such an undertaking. From some criticisms, not entirely destructive, namely, that the subject matter was too theoretical or that no subject was exhaustively covered, one conclusion that can be drawn, however, is to appeal to the greatest number, such discussions must not stray too far from practical application of chemical engineering principles. Also we must recognize the fact that we are not yet serving our membership completely and that it is possible to develop a more satisfactory and satisfying program in the chemical engineering field.

† Present address: Manager, New Products Production Cellulose Products Dept., Hercules Powder Co., Wilmington, Del.

TESTING TECHNIQUES

(*Continued from page 58*)

erable progress in 1951 on the objectives of the Testing Techniques and Equipment Performance Standards Committee of A.I.Ch.E. During the year it was agreed that formal procedure for approval of codes was a necessity, and a tentative outline of such a procedure was worked out. Public meetings for reading the approval of codes were thought unnecessary and have been eliminated.

In the procedure adopted the code will be set up by a subcommittee with drafts submitted to the main committee and other interested organizations and experts for criticism and comment. Redrafts of proposed codes will be drawn by the subcommittee in the light of criticism and suggestions for improvements. The redraft will go again to the main committee for examination and voting and all negative votes must be accompanied by detailed reasons and suggested improvements. Upon completion of final draft it will be approved by Council and published.

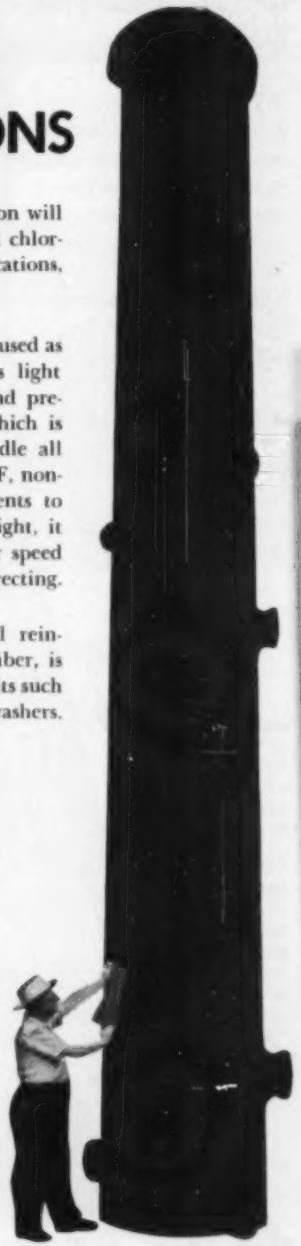
Dixon also reported that the code on Sensible Heat Transfer is now in the final stages of preparation for publication. A draft of Section II of the code covering testing and condensing equipment has been submitted to the main committee and to industry for comment.

The subcommittee on agitators is at present limiting itself to classification of nomenclature, types of equipment and applications, and an evaluation of available testing techniques in the literature. Other subcommittees reported on by Dixon were those on evaporators, which are now discussing the scope of the code; the pump subcommittee, now examining the difference between Hydraulic Institute Code and the revised A.S.M.E. code for centrifugal pumps. The committee on dryers has reached a tentative classification, and is now drafting a code for tray and rotary dryers according to Mr. Dixon's report. The committee on absorbers has developed a single code which has been reviewed by the main committee and by equipment manufacturers and industry users. The final draft is being prepared and will be resubmitted shortly to the main committee. The committee on distillation equipment is now reviewing a draft of a code listing points which should be given consideration in the design and sale on a distillation column.

W. T. Dixon has retired as chairman and W. R. Marshall, associate professor of chemical engineering at the University of Wisconsin, is the new head of the committee. In addition the name has been changed by Council for Committee on Testing Techniques and Equipment Performance Standards, to Equipment Testing Procedures Committee.

Light Weight and Corrosion Proof

PERMANITE CONSTRUCTIONS



This tower of Permanite Construction will handle HCl, carbon tetrachloride and chlorine. It was built to customer's specifications, is 3 ft. I. D. by 28 ft. high.

Permanite is a furfural alcohol resin used as a structural or lining material. It is light weight, but very strong and tough and presents a hard non-absorbent surface which is entirely corrosion proof. It will handle all alkalies, most acids, including HCl, HF, non-oxidizing acids, oil and organic solvents to 280° F. Being compact and light weight, it offers the added advantages of greater speed and facility in handling, shipping and erecting.

Permanite, as a structural material reinforced with Orlon or chemical glass fiber, is fabricated into complete functional units such as tanks, absorbers, towers and fume washers.

Permanite is also used:

In molded one-piece units—
such as sinks, trays, tanks, sumps.

As a corrosion proof lining (over Pyroflex membranes)
for steel, brick and concrete.

As a physical and thermal shock resistant armor—
for Knight-Ware Ceramic Pipe, kettles, heat exchangers.

As light-weight pipe and fume ducts—
in diameters from 1½" to 36". Permanite pipe may be machined, sawed and drilled.

For Complete information on Permanite, write for Bulletins: Permanite Equipment, No. 6F, Permanite Pipe and Ductwork No. 1F, Permanite HC1 Absorbers No. 7F.

Maurice A. Knight 703 Kelly Ave., Akron 6, Ohio
Acid and Alkali-proof Chemical Equipment

FOR EXACTING TECHNICAL APPLICATIONS

VITREOSIL* (vitreous silica) tubing possesses many characteristics you seek. A few of its properties are: Chemical and catalytic inertness. Usefulness up to 1000°C and under extreme thermal shock. Homogeneity and freedom from metallic impurities. Unusual electrical resistivity. Best ultra-violet transmission (in transmission quality). VITREOSIL tubing available promptly from stock in four qualities.

TRANSPARENT
SAND SURFACE
GLAZED
SATIN SURFACE

Stock sizes transparent up to 32 mm. bore, opaque to 4½" bore. Available for prompt shipment. Larger diameters can be supplied on special order.

Can be had in all normal lengths.

Send for Bulletin No. 9 for specifications and prices.

THE THERMAL SYNDICATE, LTD.
14 BIXLEY HEATH
LYNBROOK, N. Y.

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.
Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 11-13, 1952.
Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.
Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.
Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.
Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.
Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.
Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Vacuum Engineering
Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

Distribution of Chemicals
Chairman: D. A. Dahlstrom, Northwestern University, Evanston, Ill.
Meeting—Chicago, Ill.

Monobed Ion Exchange
Chairman: F. J. Van Antwerpen, Editor, Chemical Engineering Progress, 120 East 41st St., New York 17, N. Y.
Meeting—Chicago, Ill.

Applied Thermodynamics
Chairman: W. C. Edmister, California Research Corp., Richmond, Calif.
Meeting—Cleveland, Ohio

Human Relations
Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering
Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.
Meeting—Cleveland, Ohio.

Filtration
Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.
Meeting—Cleveland, Ohio

Chemical Engineering in Hydrometallurgy
Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.
Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics
Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Absorption
Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

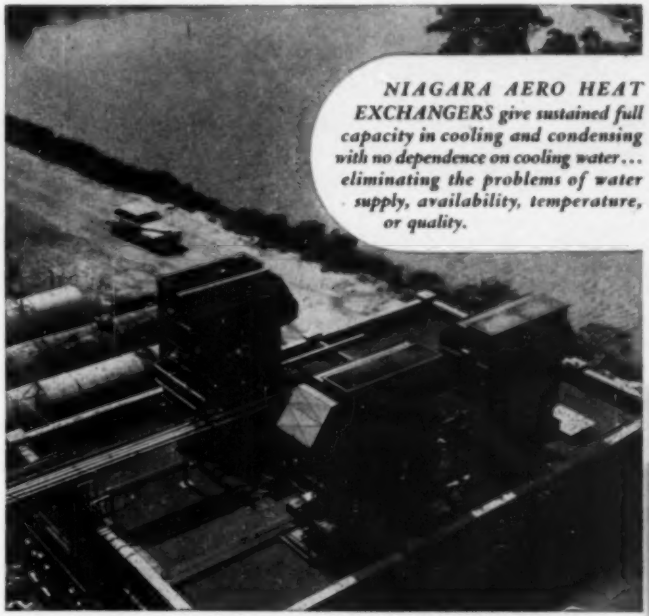
PEOPLE

William L. Rodich has been promoted to general manager of the laminated and insulating products department of General Electric's chemical division. A native of Brooklyn, N. Y., Mr. Rodich graduated in 1939 from Brooklyn Polytechnic Institute with a B.S. in chemical engineering. He went to General Electric in 1950 and subsequently became manufacturing manager of the chemical materials department and in October of last year he was named assistant general manager of the laminated and insulating products department. He is located at the headquarters of the laminated and insulating products department in Coshocton, Ohio.

Charles E. Brookes has been appointed to the sales staff of Dewey and Almy Chemical Co., Cambridge, Mass., as part of an expanded program for the production and sales of high styrene copolymer latices and resins, polyvinyl acetate emulsions, plasticizers and dispersing agents by the organic chemicals division. Mr. Brookes, before going to Dewey and Almy, sold rubber plasticizers and related products for Sun Oil Co. A chemical engineer, he obtained his degree from Yale University. In World War II he served with the infantry in the European Theater.

T. Bartow Ford has been appointed vice-president in charge of sales of the Dorr Co., Stamford, Conn., and has been elected a director of the company. Until recently he had been manager of international sales.

Mr. Ford received his degree in chemical engineering from the Georgia School of Technology in 1926 and began his work then with The Dorr Co. at its Atlanta office, first as a junior engineer, and later as manager of that office. In 1936 he was assigned to Tokyo, becoming in 1937 administrative head of the company's activities in Japan and the territories of Manchuria, Korea and Formosa. In 1941 he returned to the United States, becoming assistant manager of the company's industrial division, and in 1946, manager of international sales.


NIAGARA AERO HEAT EXCHANGERS give sustained full capacity in cooling and condensing with no dependence on cooling water... eliminating the problems of water supply, availability, temperature, or quality.

Niagara Aero Heat Exchangers at a Plant of the Heyden Chemical Corp.

Still Operations Improved by a New Cooling Method

• NIAGARA AERO HEAT EXCHANGERS cool the reflux supply or condense vapors at a vacuum by controlled evaporation of water directly on the heat exchange surfaces.

Liquid or vapor temperatures are always held constant by the Niagara "Balanced Wet Bulb" control method, which automatically varies the cooling effect proportionately to the load. The distillation is therefore uniform throughout all changes in climatic conditions the year around; it is the same in the heat of summer as in the freezing cold of winter. Continuous maximum production is thus insured.

Non-condensibles are effectively separated at the condensate outlet, with notable sub-cooling after separation for greater vacuum pump efficiency.

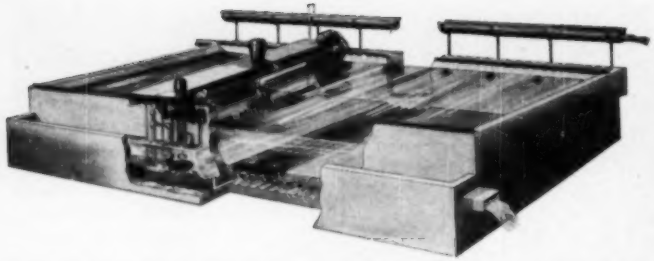
Use of Niagara Aero Heat Exchangers reduces your operating costs and removes many sources of your troubles in distillation column operation. Ask for new bulletin #120.

NIAGARA BLOWER COMPANY

Over 35 Years Service in Industrial Air Engineering

Dept. EP, 405 Lexington Ave. New York 17, N. Y.

Experienced District Engineers in all Principal Cities of U. S. and Canada



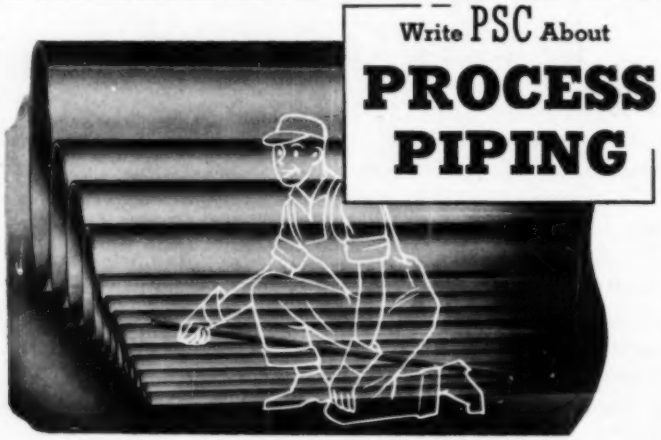
IT CLEANS ITSELF WHILE FILTERING!

The HARDINGE AUTOMATIC BACKWASH FILTER is the sanitary engineer's dream come true! . . . a sand filter which cleans itself—automatically—with no interruption whatever to the filtering operation. No shutdown or changeover is necessary while cleaning is in progress. The secret of this remarkable filter lies in its special, compartmented filter bed and traveling backwash mechanism which automatically cleans and removes the sludge from one compartment at a time—on a pre-determined time cycle or with increase in head pressure. And . . . it's highly efficient, removing 75% to 80% of the suspended solids—90% or better if chemicals are added. Bulletin 46-40.

HARDINGE
COMPANY, INCORPORATED

YORK, PENNSYLVANIA—240 Arch St. Main Office and Works

NEW YORK 17 • SAN FRANCISCO 11 • CHICAGO 6 • HIBBING, MINN. • TORONTO 1
122 E. 42nd St. 24 California St. 205 W. Wacker Dr. 2016 First Ave. 200 Bay St.



Write PSC About
PROCESS PIPING

Fabricated from Complete Range of Alloys, Any Diameter Up to 60", and in Any Shape

PSC welded process tubing is furnished in any alloy whatsoever. This feature accounts for its wide application in meeting the unlimited variety of heat, corrosion, oxidation conditions in process plants.

Any diameter up to 60"; wall thicknesses to 3/8"; temperatures to 2200°. Precision fabrication of tubing assemblies is a specialty. Send b/p or write us to your needs.

THE PRESSED STEEL CO., 708 N. Penna. Ave., Wilkes-Barre, Pa.

Custom Fabricators for the Process Industries Since 1928. Send Your Blue Prints

T. W. Nelson has been appointed effective March 1, associate director of Socony - Vacuum's laboratories, according to an announcement by Magnolia Petroleum Co., a Socony-Vacuum affiliate. He will make his headquarters in New York and will be responsible for the coordination of research in laboratories at Paulsboro, N. J.; Brooklyn, N. Y., and at Dallas.

Nelson has been director of Magnolia's field research laboratories at Dallas for the past six years. He was graduated from the Colorado School of Mines in 1934 with a degree in petroleum engineering. That year he began work in the technical department of Socony-Vacuum's refinery at Augusta, Kan. After service there and at the company's research and development laboratories at Paulsboro, he became director of the Dallas laboratories. During the war Nelson served on technical committees in the aviation program of the Petroleum Administration for War.

Fred Olsen has been appointed vice-president for research and development of Olin Industries, Inc. Dr. Olsen is also an Olin director and has been the director of research and development.

He has been with the Olin organization since 1929 and has worked in the development of stable nitrocellulose and in "ball" powder, which is produced by a revolutionary "under water" process, and with cellulose and high explosives.

R. J. Kunz, former chief engineer of the special products division, of The Borden Co., has been appointed director of production and engineering. Dr. Kunz has been associated with The Borden Co. since 1945. Prior to that he was with Hoffman-LaRoche, Inc., as director of chemical engineering development, and during World War II he served as director of division 10.1 N.D.R.C. project at The Northwestern Technological Institute, Evanston, Ill.

BAMAG

There's **NO SUBSTITUTE FOR EXPERIENCE**

Consult **GIDCO**

for Bamag's 80 year engineering and process equipment know-how

- Nitric acid plants including direct oxidation by pure oxygen for the manufacture of high concentrated acid
- Fertilizer Plants
- Recovery of waste pickling acids in steel mills
- Recovery of sulfur from Petroleum and Gases including Sweetening Alkacid Plants
- Treatment of fish oil for its use as edible oil and fats
- Wecker plants for increase of yields in existing oil refineries
- Refining and Hydrogenation of oils
- Electrolysers for Hydrogen and Oxygen
- Steel Mill Equipment
- Equipment for Water Treatment

WRITE FOR DESCRIPTIVE LITERATURE

GENERAL INDUSTRIAL DEVELOPMENT CORPORATION

Exclusive Agents for

BAMAG-MEGUIN

270 PARK AVE. • NEW YORK 17, N. Y.

Frederick B. Grosselfinger has been appointed technical director by the Synthetic Nitrogen products Corp., New York. From the time of his graduation from Massachusetts Institute of Technology, where he received both his baccalaureate and masters degrees in chemical engineering, Mr. Grosselfinger has been engaged, except for war service, in work in the chemical field. From M.I.T. in 1939 he went with the M. W. Kellogg Co., where he was employed in the process engineering department.

In 1941 Mr. Grosselfinger joined the Signal Corps, and served five years in the Army. Upon separation from the Army, he joined Hydrocarbon Research, Inc., in New York and worked on process development and sales engineering. This involved petroleum refining, petrochemicals, synthetic fuels, ammonia synthesis and gasification of coal. One year was spent in work with the Atomic Energy Commission.

R. E. VIVIAN GOES ON SPECIAL MISSION

R. E. Vivian, dean, college of engineering, University of Southern California, is on sabbatical leave until September, 1952. He has accepted an appointment as chemical production specialist with the Mutual Security Agency in a special mission for economic cooperation with Italy and France. He will divide his time between the two countries and may be reached at the American Embassy in either Rome or Paris.

Daniel L. Pastell of the Du Pont Co.'s petroleum laboratory staff has been awarded the 1950 Horning Memorial Award of the Society of Automotive Engineers. It is given annually to the author of the best paper on the adaptation of fuels to internal combustion engines. A graduate of the University of Washington, Mr. Pastell joined the staff of the petroleum laboratory of the Du Pont Co.'s organic chemicals department, in 1947. He became leader of the combustion research group of the petroleum laboratory in 1950 and in this capacity supervises engine research on combustion.

Elmer P. Foster recently left the Grasselli (N. J.) department of the Du Pont Co. and is associated now with the atomic energy division of the company's explosives department. He is located in Wilmington, Del.

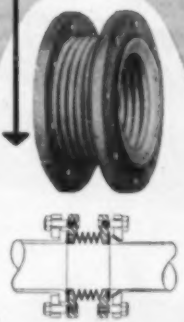
(*More About People on page 66*)

CHEMISEAL

MADE OF TEFLON

EXPANSION JOINTS

1. Chemical and contamination proof.
2. Correct mis-alignment.
3. Absorb vibration and pipe-line expansion and contraction.



Chemiseal Expansion Joints, fabricated from Teflon® by a special United States Gasket Company process, will handle all fluids that glass or other chemical resistant piping and equipment can handle, without corrosion, contamination, danger of leaking or bursting.

Designed for 25 lb. pressure and temperatures from—110°F. to 500°F., there are types for conical-end glass fittings, glass lined assemblies and for standard 125 lb. or 150 lb. A.S.M.E. integrally-gasketed flanges. Ask for catalog No. 212. For special conditions supply pertinent data.

Fluorocarbon Products Division

UNITED STATES GASKET CO.

CAMDEN 1, NEW JERSEY

"duPont's trademark for its tetrafluoroethylene resin

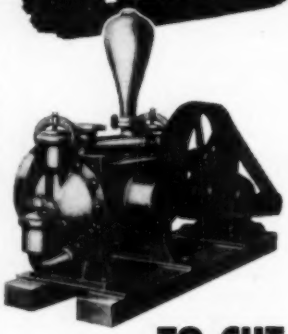
FABRICATORS OF "TEFLON", "KEL-F" AND OTHER FLUOROCARBON PLASTICS

An Ever-Growing Number of Plants Pumping . . . . . .

√ *Slurries • Sludges*
√ *Corrosive • Abrasive*
√ *Viscous • Thick*
√ *Heavy • Valuable*
√ *Delicate or Hazardous Materials*

are installing

SHRIVER Diaphragm Pumps



TO CUT *Operating and Maintenance Costs*

Because in this double reciprocating, positive action pump, heavy rubber or synthetic rubber diaphragms separate the liquid ends (and the materials handled therein) from the working mechanism. Thus, there can be no wear of the lubricant-immersed mechanism or contamination of the fluid. No packings, no leakage, no waste of materials, nuisance or hazards. Replacements and maintenance are minimized.

Liquid ends may be made of any metal or lining; pressures to 100 p.s.i.; capacities to 90 g.p.m. Hundreds of users' reports emphasize that Shriver Diaphragm Pumps "can really take it" and last longer.

Write for Bulletin No. 126

T. SHRIVER & CO., Inc.
812 Hamilton St. • Harrison, N. J.

Keith E. Rumbel has joined the staff of chemical engineers at Atlantic Research Corp., Alexandria, Va. An announcement to this effect was made recently by Arch C. Scurlock, president of the chemical engineering and research firm. Previous to his appointment at Atlantic Research, Mr. Rumbel held the post of assistant professor at the Massachusetts Institute of Technology, and was also Director of the M.I.T. School of Chemical Engineering Practice, Buffalo Station.

Blaine K. McKee, recently of Mellon Institute, has joined the staff of M. K. Mellott & Co., Pittsburgh public relations firm. Dr. McKee is a registered professional engineer in Pennsylvania and spent eight years at Mellon Institute in chemical research. Prior to that, he was employed in technical capacities for three years by firms in the steel and glass industries. A graduate of the University of Pittsburgh.

J. W. McCaslin has been promoted to a new position within the Phillips Petroleum Co.'s organization. His new position is that of supervisor of the health physics branch of the Atomic Energy division. This division, located in Idaho Falls, Idaho, is under contract with the A.E.C. for the operation of its materials testing reactor.

R. C. Ernst, dean of the Speed Scientific School, and president and director of the University of Louisville Institute of Industrial Research, was elected president of the Kentucky Society of Professional Engineers at its annual meeting held recently at the University of Kentucky.

George Karnofsky, inventor of the Rotocel Extractor, has been appointed assistant to the director of research for Blaw-Knox Co.'s chemical plants division. Mr. Karnofsky joined Blaw-Knox in 1943 and has been active on the research staff of the company's fabricating division at Blawnox, Pa. Prior to his contact with Blaw-Knox, Mr. Karnofsky was engaged for five years in developmental work for a major oil company.

MERCOID
SOLVES INDUSTRY'S AUTOMATIC CONTROL PROBLEMS

THE ONLY 100% MERCURY SWITCH EQUIPPED CONTROLS

The distinguishing feature of Mercoid Controls is the exclusive use of Mercoid hermetically sealed mercury switches. These switches are not subject to dust, dirt or corrosion, thereby assuring better performance and longer control life.

If you have a control problem involving the automatic control of pressure, temperature, liquid level, mechanical operations, etc., it will pay you to consult Mercoid's engineering staff—always at your service.

Complete Mercoid Catalog sent upon request.

THE MERCOID CORPORATION, 4201 BELMONT AVE., CHICAGO 41, ILL.

RECORDERS
RECORD TIME COUNT QUANTITY AND WEIGHT

Actuated by an electrical impulse . . . operates on the output of a scaler, photo tube, limit switch or any similar device. Records counts with relation to time and quantity on a roll of tape . . . automatically resets to zero.

In Radioactive Research, it saves precious man hours and results in greater economy and efficiency.

In Industry, it maintains a permanent record automatically, recording production and time each hour.

Whatever your counting problems, our Engineering Department can adapt these Recorders to meet your particular need.

Write for interesting Booklet SC27

WEIGHT RECORDERS
SCALES
HI-SPEED COUNTERS

AUTOMATIC WEIGHT RECORDERS SINCE 1930

STREETER-AMET COMPANY
4101 RAVENSWOOD AVENUE
CHICAGO 13 • ILLINOIS

Necrology

S. C. DIXON

Samuel C. Dixon, chemical engineer with The M. W. Kellogg Co., New York, died Feb. 23. Graduated from Cooper Union with a B.Ch.E. in 1941, Mr. Dixon lectured in the Evening Session (1949) of the Chemical Engineering department of the College of the City of New York on fuels and lubricants, in addition to carrying on his regular work at Kellogg. Prior to his graduation from Cooper Union he was associated with Binney & Smith Co., New York, and the Gefro Supply Co., West New York, N. J. Later he served as laboratory assistant at C.C.N.Y. He was born in New Jersey 40 years ago.

F. P. LASSETER

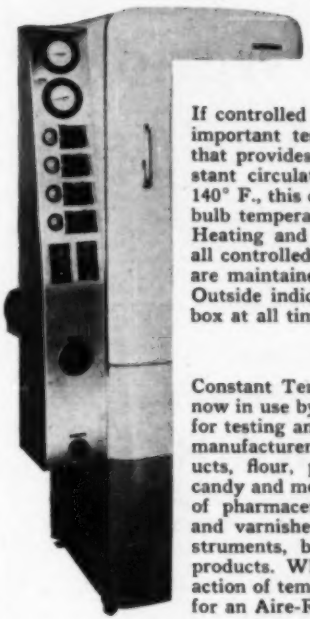
Franklin Powell Lasseter, associated with the Dorr Co. since 1936, died Feb. 16, 1952. He received a Ph.D. in chemical engineering from Columbia University. Early in his career he was associated as a Fellow with the Mellon Institute for two years on flocculation and clarification work, and four years on coal technology. Subsequently he went with Dorr as research chemist and chemical engineer. More recently he served Dorr in Atlanta, Ga., as sales engineer. Mr. Lasseter was born in Alabama in 1896.

J. CLARENCE LOTTES

J. Clarence Lottes, 38 years, associate professor of chemical engineering at Purdue University, died recently. He received a B.S. in chemical engineering from Purdue University in 1935 and the Ph.D. in chemical engineering in 1949. Between these two degrees he spent three years with the Tennessee Eastman Corp. working on plasticizers. During World War II Dr. Lottes was in the service of the United States Navy engaged in research at Washington, D. C. with the rank of Lieutenant. At Purdue University he played a leading roll in teaching chemical process industries.

B. G. KLUGH

Bethune G. Klugh, consultant to Monsanto Chemical Co., died in Birmingham, Ala. recently. He was associated with Monsanto since 1938. Subsequent to two years study at the University of South Carolina and two years at the University of North Carolina he was engaged in mining engineering work, and served with the Pioneer Iron Co., at Marquette, Mich., Carnegie Steel Co., Toledo Furnace Co., and American Ore Reclamation Co.



HUMIDITY

Within 1° Wet Bulb

If controlled air conditions are necessary for some important testing and research, here is a cabinet that provides 6 cubic feet of controlled air in constant circulation. Within the range of 40° F. to 140° F., this cabinet will maintain both dry and wet bulb temperatures within 1° F.
Heating and cooling, humidifying and drying, are all controlled automatically and uniform conditions are maintained as long as the unit is in operation. Outside indicators reveal the conditions inside the box at all times.

AIRE-REGULATOR

Constant Temperature and Humidity Cabinets are now in use by prominent laboratories in many lines for testing and research. Among the users are food manufacturers of all kinds producing bakery products, flour, packaged mixes, cheese, yeast, beer, candy and meat products; others are manufacturers of pharmaceuticals, photographic supplies, paints and varnishes, chemicals, insulating materials, instruments, box board, paper tape and crude oil products. Wherever there is a need for checking the action of temperatures and humidity there is a need for an Aire-Regulator.

Write for bulletins and tell us your requirements.

Food Technology, Inc. 5907 NORTHWEST HIGHWAY CHICAGO 31, ILLINOIS

you can
RAISE FILTRATE QUALITY
LOWER MAN-HOUR COST
with
CHEMICAL
ADAMS FILTERS
● Para-Stone or Para-Carbon permanent filter media for ideal filter aid support.
● Backwash without disassembly or removal of any part. Filter is on-stream again in minutes.
● Hydraulic davit lifts free-swinging cover for inspection (optional). NO HOOKS, CHAINS OR HOISTS NEEDED.
● Complete package, single filter or battery, includes filter aid precoat tank, continuous filter aid feeder, pressure backwash tank, pump, valves and piping.
Write for your copy of Bulletin 430
R. P. ADAMS CO., INC.
240 PARK DRIVE
BUFFALO 17, N. Y.

CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion (about 36 words) free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at $15 per inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone OREgon 9-1560. Advertisements for this section should be in the editorial offices the 20th of the month preceding the issue in which it is to appear.

SITUATIONS OPEN

VISCOSE ENGINEER

National organization seeks capable graduate engineer with experience in viscose rayon manufacture or related experience. Headquarters New York. Salary open.

Send complete resumé including age and salary data.

Box CEP 698, 221 W. 41 St., N. Y. C. 18

CHEMISTS AND CHEMICAL ENGINEERS

Thinking of Changing Jobs?

We're not an employment agency, but clients of ours have some challenging jobs open in Research and Development—perhaps the opportunity you are looking for. They don't promise the world; they know, just as you do, that the right man, right job, and work all team together to insure a sound future for the company and for you.

If you are interested in a future in research and development, why not call or write us and tell us something about yourself? No obligation and obviously confidential.

ROGER WILLIAMS, INC.

Economic Studies • Market Research • Public Relations

148 East 38th Street, New York City 16 • MUrray Hill 5-6508

SALES REPRESENTATIVE—Established Mid-West manufacturer of corrosion proof equipment desires a manufacturer's representative in the Chicago area. Experience necessary selling chemical industry. Financial aid available to right party. State experience, education and other lines handled. Box 2-3.

Expanding heavy chemical manufacturing company in Los Angeles area requires several graduate chemical engineers and chemists from accredited schools to enter training program. Excellent opportunity for successful candidates. No experience required. Write Box 5-3 for interview stating education, experience, personal history, etc.

WANTED—Chemical Engineers at all levels for research and development work on wide variety of industrial projects in research foundation in Southwest. These are permanent positions. Send complete details. Box 6-3.

PRODUCTION ENGINEER

Alkali - Chlorine experience required. Successful with personnel, production and costs. Small plant located Mid-South. Letter should cover background in detail and state salary expected. Box 3-3.

ENGINEER

Recent graduate, mechanical or chemical engineer with some design experience, preferably in chemical manufacturing plant. State details of education, experience, military status and salary expected. Box 4-3.

OPPORTUNITIES FOR EXPERIENCED TECHNICAL PERSONNEL IN ATOMIC ENERGY INSTALLATIONS AT

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Electromagnetic Separation Plant
Oak Ridge, Tennessee

Gaseous Diffusion Plants
Oak Ridge, Tennessee & Paducah, Ky.

ENGINEERS

DESIGN - DRAFTING — chemical plants, structures, piping, valves, utilities, alterations.

LABORATORY — research and development.

POWER—design, testing, construction of large electrical power generation and distribution installations.

MACHINE DESIGN — jigs, fixtures, gadgets, remote control equipment.

PROCESS—chemical process and equipment design, vacuum or high-pressure systems, pilot plant and production operation.

CONSTRUCTION — plant design, specifications, sub-contractor liaison.

SAFETY — pressure vessel inspection and fire protection.

NUCLEAR REACTORS — design, development, construction, testing.

INSTRUMENTATION — design development and industrial application of electronic and pneumatic instruments.

INDUSTRIAL AIR - CONDITIONING AND REFRIGERATION—design of plant systems.

CHEMISTS, PHYSICISTS, METALLURGISTS

Research, development, and production in nuclear technology, gaseous diffusion, and related fields.

Minimum educational requirement —B.S. degree, or its equivalent.

Salary commensurate with training and experience.

Give experience, education, age, references, personal history, salary received and salary expected.

Central Technical Personnel Office
Carbide and Carbon Chemicals Company
a Division of
UNION CARBIDE AND CARBON CORPORATION
Post Office Box P
Oak Ridge, Tennessee

CHEMICAL ENGINEER—With design and operating experience in chemical industry. Knowledge of thermodynamics essential. Must have a record of accomplishments. Unlimited and unusual opportunity for advancement with an established fast growing, progressive company in eastern Pennsylvania. Starting salary $550-$600 mo. Box 24-3.

DOCTORS OF PHILOSOPHY

One man experienced in chemical engineering and one in metallurgy, as project supervisors of expanding Ohio research and development laboratory. Challenging work. Bonus plan. Advise full background, availability, references and salary requirements. Box 25-3.

CHEMICAL ENGINEERS—For process engineering, design and development with large progressive chemical company. Location northern West Virginia. Can use both experienced men and recent graduates. Write giving full details to Box 26-3.

PROCESS DESIGN ENGINEERS—Men with advanced degrees in chemical engineering or suitable experience for process design engineering with West Coast research and development company. Experience in process design of petroleum refining or organic chemical process plants particularly desirable. Write giving education, experience and personal history. Box 27-3.

DESIGN ENGINEER
SAN FRANCISCO AREA

Engineering graduate, Registered M.E., experience in chemical, petroleum or related plant process equipment and piping design. Replies confidential.

Permanent

SALARY OPEN

THE DOW CHEMICAL COMPANY

P. O. Box 351, Pittsburg, California

Attention: R. B. Ralph

FOR SALE
TWO UNUSED EFCO HEAT EXCHANGERS

Type HR Shell and Tube

Surface—580 sq. ft.; Length 20 ft.

	Shell Side	Tube Side
Design Pressure	1300 PSI	75 PSI
Design Temp.	200 F	150 F
Hydrostatic Test Pressure	1950 PSI	115 PSI
No. of Passes	one	one

No. of Tubes: 148 Size: ¾ " O.D. 12 BWG

Tubes of Inhibited Admiralty ASTM B-111

Equipment is new and bears API-ASME Stamp. Located at Coatesville, Pa. Prompt reply on all bona fide inquiries. Write or wire.

J. F. PRITCHARD & CO.

Dept. C-2 908 Grand Ave.

KANSAS CITY, MISSOURI

CHEMICAL PROCESS ENGINEER

We have an excellent opportunity for a chemical engineer with process control experience in the petroleum, petrochemical and general polymer fields with an interest in instrumentation. A knowledge of infrared analysis is desirable but not essential.

This engineer is needed to assist in the development of plant control infrared analyzers and to take charge of application engineering problems.

Applicants should write giving complete statement of qualifications to:

Personnel Manager

THE PERKIN—ELMER CORP.

Main Ave., Norwalk, Conn.

SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL ENGINEER — Experienced in handling design and erection for the complete plant as project engineer. Bulk of experience in detergents, pharmaceuticals, and organic chemicals. Seeking position as chief engineer. New York area. Box 1-3.

CHEMICAL ENGINEER — M.S.E. Univ. of Michigan. M.S. Chemistry. Age 32. Eight years diversified experience in production, research and development. Good initiative and drive. Not U. S. citizen. Desire position anywhere in the world. Box 7-3.

CHEMICAL ENGINEER—B.S., 31. Five years' design, development, production supervision experience. Responsible, Industrious. Desire North Eastern location. Will accept work in above, sales or administration. Box 8-3.

CHEMICAL ENGINEER — Registered Ohio, thirteen years' industrial experience, research, development, production, sales domestic and export. Age 34, married, Protestant, member A.C.S. and A.I.Ch.E. Seeking association with small or medium size organization needing man to assume major responsibilities. Wish to acquire interest in business. Currently employed New York City. Will move. Box 9-3.

CHEMICAL ENGINEER—Two years' experience. Two years graduate work. Married, 24, must be in essential industry. Seeking process engineering work. New York or Chicago area preferred. J. Busch, 375 Riverside Drive, New York City 25.

CHEMICAL ENGINEER—Twelve years' engineering experience includes process and design engineering and production supervision in petrochemical and inorganic chemical plants. Will undertake pilot plant operation prior to assuming supervisory position. Houston area. Box 10-3.

CHEMICAL ENGINEER-BUSINESS MAJOR—B.S.Ch.E. 1945; M.B.A. June, 1952; 28; family. Six years' diversified experience including process development, production supervision and sales engineering. Desire position in technical sales or production management. Box 11-3.

ACADEMIC POSITION—Chemical Engineering Ph.D. Age 33, family. Seven years' teaching, industrial and consulting experience. Publications. Excellent thermodynamic background. Minimum salary requirements, $6,000 on nine-month basis. Summer employment also essential. Available June. Box 12-3.

PROCESS DEVELOPMENT CHEMICAL ENGINEER—Fifteen years' experience in pilot plant evaluation, research, and new plant operation in lub. oil refining, synthetic fuels, coal tar chemicals, and alcohol based chemicals. Am registered. Location immaterial. Box 13-3.

CHEMICAL ENGINEER — Ph.D., February, 1952, Alien. Age 29, married. Training in mechanical and chemical engineering fields. Diversified research experience. Research and development work desirable. Box 14-3.

(More Ads on page 70)

Foam's a Fraud...Kill it With

DOW CORNING ANTIFOAM A

To get the most out of your process equipment, add a trace of Dow Corning Antifoam A and use the space you've been wasting on foam. You'll process most of your most violent foamers, even under vacuum or continuous heat, without waste or hazardous overflow.

That's because Dow Corning Antifoam A kills foam faster and in a wider variety of foamers than any other material known. Practically odorless, tasteless and non-toxic, it is safe to use in food and drugs at concentrations up to 10 parts per million—many times the concentrations normally required.

That kind of efficiency makes Dow Corning Antifoam A the most economical as well as the most versatile defoamer available.

See for Yourself

Send Coupon Today for Your FREE SAMPLE

DOW CORNING SILICONES

Dow Corning Corporation, Dept. AS-15 Midland, Michigan

Please send full information and a free sample of Dow Corning Antifoam A.

Name_____

Company_____

Address_____

City_____ Zone____ State_____

DOW CORNING CORPORATION

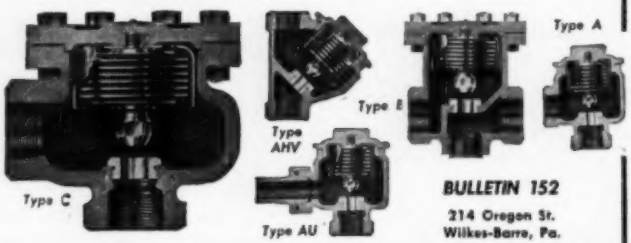
MIDLAND, MICHIGAN

ATLANTA • CHICAGO • CLEVELAND • DALLAS • LOS ANGELES
NEW YORK • WASHINGTON, D. C.

Nicholson Traps Help

CUT STEAM COST $500,000 A YEAR

At one of the nation's large processing plants a campaign to promote economical steam use by improving heat transfer efficiency has resulted in a yearly saving of $500,000. Credit for a fair portion of this is given to improved steam trapping, which resulted from the installation of Nicholson thermostatic traps. To see why an increasing number of leading plants are standardizing on Nicholsons for positive drainage and faster heat transfer, send for Bulletin 152.



BULLETIN 152
214 Oregon St.
Wilkes-Barre, Pa.

W. H. NICHOLSON & CO.
TRAPS · VALVES · FLOATS

MARTINDALE PROTECTIVE MASKS

PLACE HEADBAND WELL UP AROUND HEAD TO KEEP FROM SLIPPING DOWN
PRESS NOSE TABS IN CLOSE AGAINST FACE TO HOLD PAD AGAINST THE NOSTRILS
PRESS EDGES OF FACE PLATE DOWN TO FIT FACE SNUGLY

Weigh less than ½ ounce

These light-weight aluminum masks provide protection against over 400 dusts such as wood, coal, lime, salt, cement, grain, rust, paper, textiles, some insecticides, paint spray from non-toxic paints, etc.

Pads can be changed in a few seconds. Only clean gauze touches the skin. Comfortable to wear. Workers like them.

Martindale Protective Masks....$.30 ea.
No. 1 Refills (Standard weight) .02 ea.
No. 2 Refills (Heavyweight) .02½ ea.

Write for quantity discounts

MARTINDALE ELECTRIC CO.
1322 Hird Ave.,
CLEVELAND 7, OHIO

PLATE FABRICATION

CHROME IRON ALLOYS
CARBON STEEL
CHROME NICKEL
SILICON BRONZES
MONEL • ALUMINUM
NICKEL CLAD STEEL • ETC.

Towers, Pressure Vessels and General Plate Fabrication manufactured with trained personnel and up-to-date equipment. Our Engineers will assist in designing to meet your requirements.

Good Design — Right Material — Expert Workmanship at a Fair Price.

HEAT EXCHANGERS A SPECIALTY

Fabricators and Designers for More Than 30 Years

Use our valuable new Bulletin as a handy reference guide . . . contains partial analysis of 1950 A.S.M.E. Code for Unfired Pressure Vessels.

DOWNINGTOWN IRON WORKS, INC.
DOWNINGTOWN, PA.
STEEL & ALLOY PLATE FABRICATION
HEAT EXCHANGERS

CHEMICAL ENGINEERS FOR BRAZIL—Two veterans with B.S.Ch.E. and experience in refinery process design, purchasing, construction, and operation desire positions in responsible capacity located in Brazil. Both married. Box 15-3.

CHEMICAL ENGINEER—B.Ch.E., C.C.N.Y., February, 1944. Single, 31. Three years' experience in acid development, production, pilot plant operations, steam equipment, etc. Six months of graduate schooling were just completed. Prefer Eastern location. Résumé available. Box 16-3.

CHEMICAL ENGINEER—B.S., M.S., Ph.D. (June). Married, 30, veteran. Experience in operations research, general production, instrumentation, electronics. Desire position in research, production trouble-shooting, technical engineering, or other leading into administration. Background: petroleum, natural gas, generally unspecialized. Prefer Middle West or West. Box 17-3.

REGISTERED PROFESSIONAL ENGINEER—Age 35. Desire sales or supervisory engineering position. Tau Beta Pi. Active member A.I.Ch.E., I.S.A., A.C.S. With experience of progressively greater responsibility. Two years research, three years development, five years engineering, three years sales. Familiar with instrumentation petroleum and petrochemical processing. Minimum acceptable salary $10,000. Box 18-3.

DISTRICT SALES MANAGER — Fabricated process equipment, mixers, kettles, dryers, heat transfer, etc. Engineering of complete plants. Nineteen years' engineering sales and managerial experience. Extensive acquaintanceship New York and East Coast. Licensed engineer. Box 19-3.

CHEMICAL ENGINEER—B.Ch.E., 27. Five years' diversified chemical process design and development experience. Evening graduate student for M.S. in industrial engineering. Desire opportunity in production and/or plant management with progressive manufacturer. N. Y. metropolitan area. Box 20-3.

CHEMICAL ENGINEER—28, single, B.Ch.E. degree New York University, graduate studies toward M.S. in chemical engineering at Columbia University. Honors, societies, etc. Experience in handling plant personnel, supervisory plant process control, some development and design. Exceptionally well-qualified in "engineering sense" essential to development and achievement of new processes. Desire position in development and/or research, $6000-6500 per year. Will also consider foreign position at substantially higher salary. Box 21-3.

CHEMICAL ENGINEERING EXECUTIVE—Fourteen years' experience development, production management in all phases of organic chemical manufacture with foremost lubricating oil additive firm. Desire position with broad responsibility where initiative, administrative ability and leadership can be utilized to fullest extent. Age 36, B.S.Ch.E., 1937. Available immediately. Box 22-3.

Nonmembers

CHEMICAL ENGINEER—Desire greater opportunity. Experienced in heat transfer, both sales and engineering, in industrial, oil refining, and marine. Oil refining and by-product coke plant operation experience. Box 23-3.

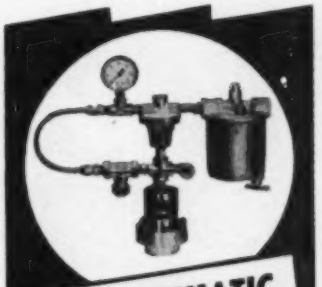
FOR PROGRESS---

use *Chemical Engineering Progress.*

C.E.P. Classified Section is the answer to the age-old question of where to *get the best* in chemical engineers.

INDEX OF ADVERTISERS

	Page
A	
Adams Co., Inc., R. P.	67
Aldrich Pump Co.	24
American Pulverizer Co.	40
Artisan Metal Products, Inc.	40
Atlas Mineral Products Co.	51
B	
Barnstead Still & Sterilizer Co.	52
Bartlett & Snow Co., The C. O.	9
Bauer Bros. Co.	42
Beckman Instruments, Inc.	46
Binks Manufacturing Co.	54
C	
Carbide & Carbon Chemicals Co., A Division of Union Carbide and Carbon Corp.	*Inside Front Cover*
Coleman Instruments, Inc.	54
Cooper Alloy Foundry Co.	17
Corning Glass Works	12, 13
Crane Company	8
Croll-Reynolds Co., Inc.	71
D	
Dow Chemical Co.	53
Dow Corning Corp.	69
Downingtown Iron Works	70
Duralay Co.	36
F	
Filtration Engineers, Inc.	44
Fischer & Porter Company	34
Fluor Corp., Ltd.	19, 20
Food Technology, Inc.	67
G	
General American Transportation Corp.	114
General Industrial Development Corp.	65
Girdler Corp.	43
Great Lakes Carbon Corp.	6
Gump Company, B. F.	3
H	
Hardinge Co., Inc.	64
Haveg Corp.	15
Hills-McCanna Co.	59
I	
Infilco, Inc.	58
Instruments, Inc.	71
International Nickel Co., Inc.	27
J	
Johnston Pump Co.	7
Johns-Manville	22
K	
Kinney Manufacturing Co.	18
Knight, Maurice A.	61
L	
Lawrence Machine & Pump Corp.	45
Little, Inc., Arthur D.	41
Lummus Co.	14
M	
Martindale Electric Co.	70
Mercoid Corp.	66
Miller, Inc., Ray	44
Milton Roy Company	*Inside Back Cover*
Minneapolis-Honeywell Regulator Co.	10, 11
Mixing Equipment Co., Inc.	*Back Cover*
N	
Niagara Blower Co.	63
Nicholson & Co., W. H.	70
P	
Pacific Valves, Inc.	38
Parks-Cramer Co.	56
Patterson Foundry & Machine Co.	38
Pfaudler Company, The	28
Pfizer & Co., Inc., Chas.	72
Pressed Steel Co.	64
Pritchard & Co., J. F.	26, 56
Proportioneers, Inc.	39
R	
Read Standard Corp.	35, 55
S	
Sharples Corp., The	16
Shriver & Co., Inc., T.	66
Sinclair Research Laboratories, Inc.	4, 5
Sparkler Mfg. Co.	57
Standard Electric Manufacturing Co., Inc.	42
Stephens-Adamson Mfg. Co.	23
Streeter-Amet Co.	66
Struthers Wells Corp.	25
T	
Thermal Syndicate, Ltd.	62
Trane Co.	33
U	
Union Carbide and Carbon Corp., Carbide and Carbon Chemicals Co.,	*Inside Front Cover*
United States Gasket Co.	65
U. S. Stoneware Co.	31
W	
Welsbach Corp.	21
Wysmont Co.	44



F/C PNEUMATIC TRANSMITTER

Ideal for measurement of level, pressure, specific gravity and differential pressure.

Materials available: steel, bronze, stainless, Haveg, Hastelloy and Monel.

Non-overloading type diaphragm. Extreme accuracy. For high or low pressure.

Write for Illustrated Bulletin

INSTRUMENTS, INC.
122 N. Madison Tulsa 6, Okla.

STRATOSPHERE PRESSURES DUPLICATED

U. S. Government Research maintains a wind tunnel at the University of California for testing parts of airplanes and rockets. In this tunnel, altitudes up to 75 miles in the stratosphere are duplicated by a five stage Evactor, a steam jet vacuum-producing unit designed and built by Croll-Reynolds to work in the range of a few microns of mercury absolute.

Croll-Reynolds five stage Evactors are built in various sizes, the smallest of which handles many times the volume of the largest mechanical vacuum pump. The same careful work and precision which produced these five stage units goes into every C-R Evactor from the one stager yielding a pressure of four or five inches of mercury absolute to the four stage unit designed for work in the range of 0.15 to 3.0 mm. of mercury absolute.

Many thousands of Croll-Reynolds Evactors are in regular operation, some of them for over 30 years. They are installed in every state of the U. S. and in many foreign countries. Let our technical staff help you with your vacuum problems, including flash cooling of water and aqueous solutions. Please address Dept. A.

C-R REYNOLDS

CROLL-REYNOLDS CO., INC.

Main Office: 751 Central Avenue, Westfield, New Jersey
17 John Street, New York 38, N. Y.

Chill-Vactors | Steam Jet Vactors | Condensing Equipment

We've Grown at Groton!

to Meet Your

CITRIC ACID

Needs!

Now Available:

CITRIC ACID U.S.P.
CITRIC ACID ANHYDROUS
SODIUM CITRATE VIII GRANULAR
SODIUM CITRATE U.S.P.
SODIUM CITRATE ANHYDROUS
FERRIC CITRATE
FERRIC AMMONIUM CITRATE U.S.P.
FERRIC AMMONIUM CITRATE N.F.
AMMONIUM CITRATE DIBASIC
POTASSIUM CITRATE N.F.

The use of citric acid as a raw material for new industrial applications . . . plus the growing requirements in food, beverages and medicinals . . . have greatly increased the demands for this chemical in recent years.

To meet these growing needs, Chas. Pfizer & Co., Inc. has recently expanded its citric acid producing facilities at Groton, Connecticut. At present, this new plant capacity assures you of ample supplies of citric acid and its derivatives. For your requirements, phone or write:

CHAS. PFIZER & CO., INC.
630 Flushing Ave., Brooklyn 6, N. Y.
Branch Offices: Chicago, Ill., San Francisco, Cal., Vernon, Cal.

Manufacturing Chemists for Over 100 Years

PFIZER

THIS MILTON ROY AUTOMATIC pH CONTROL SYSTEM DOES THE JOB...

A large Eastern rayon manufacturer maintains precise pH control, guards against rayon discoloration by iron pick-up in process water by using a Milton Roy Automatic pH Control System. Sodium silicate is the control chemical. A predetermined pH control point insures a sufficient silicate feed to coat the inside of the pipes, preventing iron oxidation and subsequent iron pick-up. Field reports show this system pin-points pH value within safe limits of plus or minus 0.2 units, eliminates rayon discoloration, effects manufacturing dollar savings.

An important component of the Automatic pH Control System—which may be supplied with all accessory control equipment—is a Milton Roy Motor-Driven Simplex Controlled Volume Pump with motorized micro adjustment of pump plunger stroke length. Stroke length is controlled automatically from a pH controller to deliver sodium silicate continuously as required.

Protection against iron pick-up by the introduction of surface active and various corrosion inhibitors while maintaining precise pH control is just one application of the principle of Milton Roy Controlled Volume Pumping. Complete systems, utilizing the metering accuracy of Milton Roy Pumps—either motor-driven or air-powered—are employed in plants for pH control of flocculation in water purification; to maintain specific materials soluble or insoluble; to prevent unfavorable side reactions in organic synthesis; to promote greater adsorption of color bodies on resins or activated carbons, or for many applications in chemical processing. Accurate volume control may be maintained using two variables, such as rate of flow and pH value.

For detailed information, call the Milton Roy representative listed in your classified telephone directory. Or write us direct.

Manufacturing Engineers

WITH THE EXCLUSIVE STEP-VALVE DESIGN

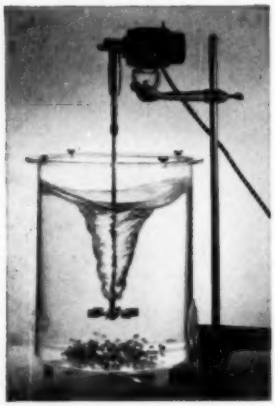
MILTON Roy COMPANY

1379 EAST MERMAID LANE, PHILADELPHIA 18, PA.

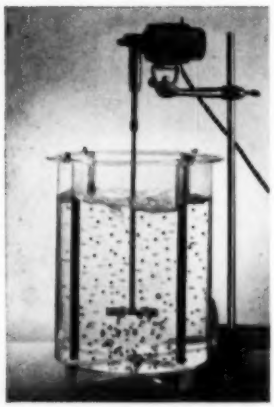
CONTROLLED VOLUME PUMPS AND AUTOMATIC CHEMICAL FEED SYSTEMS

How to get better results with

Solids Suspensions



CHECK THE AGITATOR. Does it draw a vortex like this? If so, solid particles may be heavily concentrated in tank bottom. This can mean time loss and power waste. It can cause overloading or damage to filters, pumps, other connected units in the system.

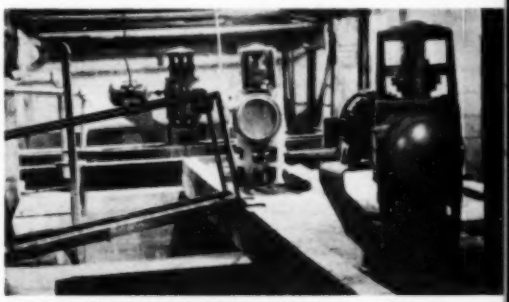


VORTEX IS ELIMINATED by properly baffling the tank, and by choosing an impeller that will efficiently lift particles of given size, density and settling rate. Result: you get the kind of suspension you want, with less horsepower, in minimum time.

MIXCO can help you get better results on any fluid agitation job—often in much less time and with less installed horsepower than you are now using, or plan to use.

In fluid agitation, remember these two facts:

- MIXCO engineers give you accurate prediction of results.
- LIGHTNIN MIXERS are guaranteed to do the job right.



THREE 10-HP LIGHTNIN MIXERS agitating a slurry in large compartmented storage tanks.

Lightnin Mixers

for every fluid agitation job

MIXING EQUIPMENT Co., Inc.

199 Mt. Read Blvd., Rochester 11, N. Y.

In Canada: William & J. G. Greey, Ltd., Toronto

Please send me the bulletins checked:

- ☐ B-102 Top Entering Mixers (turbine and paddle types)
- ☐ B-100 Condensed Catalog (complete line)
- ☐ B-78 Top Entering Mixers (propeller type)
- ☐ B-75 Portable Mixers (electric and air driven)
- ☐ B-76 Side Entering Mixers
- ☐ DH-50 Laboratory Mixers

Name_____

Title_____

Company_____

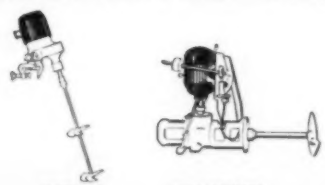
Address_____

City_____ Zone____ State_____

MIXCO

fluid agitation specialists

EVERY *LIGHTNIN* MIXER IS GUARANTEED TO DO THE JOB *RIGHT*



PORTABLE ⅛ to 3 HP

SIDE ENTERING 1 to 50 HP

TOP ENTERING 1 to 500 HP